Aalto University
School of Engineering

Sustainability Impact Assessment of Climate Change Mitigation Policies – A Case Study in Mexico

Master's Thesis
Department of Built Environment
School of Engineering
Aalto University

Espoo, 30th July 2018

B.Eng. Andrea Cecilia Cuesta Claros

Supervisor: Professor Kauko Viitanen
Advisor(s): M.Sc Anahita Rashidfarokhi,
PhD Yan Dong

Aalto University
School of Engineering

Aalto University, P.O. BOX 11000, 00076
AALTO
www.aalto.fi

Abstract of master's thesis

Author Andrea Cecilia Cuesta Claros

Title of thesis Sustainability Impact Assessment of Climate Change Mitigation Policies –A Case Study in Mexico

Master programme Master's Degree Programme in Creative Sustainability **Code** IA3026

Thesis supervisor Kauko Viitanen

Thesis advisor(s) M.Sc Anahita Rashidfarokhi, PhD Yan Dong

Date 30.07.2018 **Number of pages** 93 **Language** English

Abstract

The design, adoption, and implementation of climate policies by governments all around the world has increased in the past decades. The growing popularity of these types of policies comes as a response to the severe and irreversible impacts climate change poses to people and ecosystems, in addition to the influences from international accords such as the Paris Agreement and the Sustainable Development Goals (SDGs). Thus, climate policies are considered to be the most appropriate approach to mitigate the effects of climate change. However, these policies bear the risk of causing inadvertent impacts on humankind if they fail to be assessed in terms of the three dimensions (environmental, social, and economic) of sustainable development.

Thus, the aim of this thesis is to identify as well as assess the positive and negative impacts of a climate policy on the three dimensions of sustainable development. The climate policy that serves as a case study, is focused on energy retrofits of public buildings in the State of Jalisco, Mexico.

The author followed the Sustainable Development Guidance, developed by the Initiative for Climate Action Transparency (ICAT) as a tool to identify relevant impacts as well as qualitatively and quantitatively assess the policy. Furthermore, environmental impacts were determined through an LCA, including both in-jurisdiction impacts (i.e. state-wide) as well as out-of-jurisdiction impacts (i.e. rest of the world). Alternatively, impacts within the social and economic dimensions were only assessed locally.

The results revealed that the greatest positive environmental impacts, affecting Mexico, occurred as a result of a decrease in usage of the national energy mix, both in terms of electricity generated from the photovoltaic panels and the reduction in electricity consumption from the LED lamps. However, negative environmental impacts also took place outside Mexican borders, mainly related to the raw material extraction and manufacturing of the aforementioned technologies. The implementation of the policy yielded savings of 1,071,223 kWh corresponding to MX$2,525,365. Furthermore, the policy had a positive impact on climate change awareness of civil servants and public acceptance of energy retrofits.

Based on the research results, this thesis recommends integrating social, economic as well as other environmental impact categories (in addition to greenhouse gas emissions) in impact assessments of climate policies. It is also recommended to adopt a life cycle thinking approach when accounting for these impacts as well as to disaggregate the results based on different life cycle stages. Other recommendations are proposed: (i) the inclusion of end-of-life strategies in climate policies; (ii) the development of a climate change and/or a sustainable development governmental fund to avoid rebound effects as well as to support other like-minded projects; and (iii) the incorporation of new requirements in tendering processes which support an efficient use of materials as well as include environmental and social considerations as guiding principles.

Keywords Climate policies, sustainable development impact assessment, environmental assessment, social assessment, economic assessment, LCA, Mexico, PV panels, LED lamps, ICAT

Foreword

This master's thesis was carried out as a five-month research project for the Initiative for Climate Action Transparency (ICAT), an initiative founded as a response to the critical need of improved transparency and capacity building through frameworks that assess policy impacts. However, the conclusions included in this thesis are my own, thus not necessarily reflecting those of ICAT.

A great number of people have contributed to this thesis. To all of them, I am thankful for their willingness to share time with me. First, to Yan Dong, Anahita Rashidfarokhi, and Fatemeh Bakhtiari (my third advisor) for their valuable guidance, constant support, and for being great examples of smart, assertive as well as kind women in academia, deeply involved in sustainability matters. Second, to Kauko Viitanen, who supervised and provided feedback for this thesis as well as Michael Hauschild for the insightful discussions that helped shape this project. Third, to all the people at the UNEP-DTU Partnership as well as the DTU Management Engineering department, for allowing me to collaborate with them as a student from Aalto University. Fourth, to Soffia Alarcón-Díaz and Erika Salinas from Carbon Trust Mexico as well as Alejandro Gómez García and Arturo Palero Castro from the Ministry of Environment and Territorial Development (SEMADET) of the State of Jalisco, for their valuable inputs in addition to all the help gathering the data needed for the assessment. I would also like to thank my family, for their continuous support, which led me to pursue my master's degree in the first place, as well as Dominic and Perla, for their advice and words of encouragement throughout this project and my post-graduate studies. Last, to my fellow CS classmates, for their continuous inspiration on how to live life working for a sustainable future.

Furthermore, this research would not have been possible without the support of an academic grant provided by the Consejo Nacional de Ciencia y Tecnología (CONACYT).

Andrea Cecilia Cuesta Claros

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Abbreviations

BoM	Bill of Materials
CDM	Clean Development Mechanism
CO_2 eq	Carbon Dioxide Equivalent
CoO	Country of Origin
COP	Conference of the Parties
DALY	Disability-Adjusted Life Years
DPL	Development Policy Loans
DPO	Development Policy Operations
DTU	Technical University of Denmark
EPD	Environmental Product Declaration
ETS	Emissions Trading Systems
FL	Fluorescent Lamp
GHG	Greenhouse Gas
ICAT	Initiative for Climate Action Transparency
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISO	International Standards Organization
kg 1.4-DCB	Kilograms of 1.4-Dichlorobenzene
kg Cu eq	Kilograms of Copper Equivalent
kg oil eq	Kilograms of Oil Equivalent
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
LCSA	Life Cycle Sustainability Assessment
LED	Light Emitting Diode
MDGs	Millennium Development Goals
NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contribution
NPV	Net Present Value
OHS	Occupational Health and Safety
O&M	Operations and Maintenance
PV Panels	Photovoltaic Panels
SDGs	Sustainable Development Goals
SD Guidance	Sustainable Development Guidance
SPB	Simple Payback Time
SEMADET	Ministry of Environment and Territorial Development
SENER	Ministry of Energy
SEPAF	Ministry of Planning, Administration, and Finance
SHDB	Social Hotspots Database
SIE	Mexican Energy Information System
S-LCA	Social Life Cycle Assessment

UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WCED	World Commission on Environment and Development
WEEE	Waste Electric and Electronic Equipment
WRI	World Resources Institute

1 Introduction

1.1 Background

In recent years, climate change has not only been the focus of intense research but has also become a popular subject of political and civic action. This popularity comes as a response to the urgent and extremely complex challenges climate change poses to humankind and the Earth's systems (Harry and Morad, 2013), including 'severe, pervasive and irreversible impacts for people and ecosystems' (IPCC, 2014, p. 56).

It is extremely likely (95%) that the main cause of climate change has been the unprecedented increase of greenhouse gas (GHG) emissions as a result of human activities (IPCC, 2014). Furthermore, these human activities are strongly linked to economic and population growth, energy use, land use patterns, and lifestyles (Ibid.).

As a response, governments and international organisations have focused their efforts on both mitigating GHG emissions causing climate change and adapting to the inevitable effects of it. The most recent and popular examples include the Paris Agreement, adopted by the 21st session of the Conference of the Parties (COP21), under the United Nations Framework Convention on Climate Change (UNFCCC) and the Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, set in 2015 by the United Nations (UN). Whilst the SDGs focus on wider goals for humanity and include climate change as one of these goals, the Paris Agreement particularly focuses on national climate change mitigation and adaptation contributions.

In this vein, governments all over the world have adopted and continue to develop policies that respond to climate change (Bond *et al.*, 2001). These policies have become increasingly popular and are known as climate policies. Climate policies are top-down actions that translate climate change into an array of problems which are differently defined and dealt within a system (Ahmad, 2009).

Although climate policies are commonly considered the most appropriate way of mitigating the effects of climate change, they bear the risk of causing inadvertent impacts by ignoring that climate change is embedded in the interaction of larger environmental, social, and economic issues (Robinson and Herbert, 2001). These issues are the centre of sustainable development. Furthermore, the disconnection between climate policies and sustainable development has led to a growing concern that by not acknowledging the axiomatic nature of the latter to the former, wider societal and environmental goals would be compromised (Morecroft and Cowan, 2010).

Moreover, ignoring the complex interrelations among climate policies and the three dimensions of sustainable development, namely, environmental, social, and economic, can have the following consequences. On the one hand, if the impacts of a climate policy on sustainable development are negative, they can lead to actions that affect the well-being of humans. On the other hand, if the impacts are positive, climate policies can be at risk of not being sufficiently supported, even if they tackle multiple important issues at once. Therefore, assessing the sustainable development impacts of interventions is gradually becoming a common practice among governments and companies (Sala, Ciuffo and Nijkamp, 2015).

In the past decade, there has been a growing number of frameworks and guidance aimed towards identifying the sustainable development impacts of climate policies. Most of these frameworks have been developed by international organisations and research institutes. However, the majority of frameworks and guidance are aimed to assess policies based on specific climate change mitigation mechanisms, including the Clean Development Mechanism (CDM) and the Nationally Appropriate Mitigation Action (NAMA). Furthermore, their coverage areas commonly include national and sub-national policies, leaving specific projects, programmes, and actions without an adequate assessment tool.

A promising tool for identifying the sustainable development impacts of any policy or action (including climate policies) is the Sustainable Development Guidance (SD Guidance) developed by the Initiative for Climate Action Transparency (ICAT). This comprehensive guide, which builds upon other tools, was created by the World Resources Institute (WRI) together with a partnership between the United Nations Environment Programme (UNEP) and the Technical University of Denmark (DTU) known as the UNEP-DTU Partnership. This guidance can be used to qualitatively and/or quantitatively assess policies and actions at any governmental level, in any sector, as well as at any stage in the policy design and implementation cycle. In terms of types of interventions along the policy-making continuum, the tool is applicable 'to policy instruments and implementation of technologies, processes or practices' (ICAT, 2017, p.7). However, no studies have yet attempted to apply and evaluate this tool in actual governmental policies.

Therefore, the following three circumstances can describe the context for this thesis: (i) the generally ignored impacts of climate policies on sustainable development; (ii) the lack of frameworks and guidance available to assess these impacts at projects and programmes level; and (iii) the absence of actual policies being analysed by the ICAT SD Guidance.

1.2 Thesis aim

Considering the circumstances previously described, this thesis aims to identify and assess the impacts of a climate change mitigation policy on the three dimensions of sustainable development, namely, environmental, social, and economic dimensions, using the ICAT SD Guidance.

Thus, the main research question to be answered in this thesis is the following:

- What are the impacts of the selected climate change mitigation policy on the three dimensions of sustainable development?

This main research question will be accomplished by finding answers to five research sub-questions:

- What are the net, in-jurisdiction and out-of-jurisdiction environmental impacts of the selected climate policy? (30 years)
- What are the in- jurisdiction social impacts of the selected climate policy? (30 years)
- What are the in-jurisdiction economic impacts of the selected climate policy? (30 years)
- What are the ex-post environmental, social and economic net impacts? (5 years)
- Based on the sustainable development impact assessment, which recommendations can inform better design and implementation of future climate policies?

1.3 Scope of the study

The climate policy that serves as a case study focuses on energy efficiency retrofits of public buildings in the State of Jalisco, Mexico. The selected climate policy is called the Carbon Management Plan, which is a state-wide policy containing 96 different climate actions or projects. From these 96 actions, two of them were chosen for the assessment. The Carbon Management Plan was created as a part of Mexico's National Climate Change System and is locally managed by the Ministry of Environment and Territorial Development (*Secretaría de Medio Ambiente y Desarrollo Territorial*) (SEMADET) of the State of Jalisco.

1.4 Methodology

In order to achieve the aim of this work, this thesis will follow a case study methodology, specifically an exploratory single-case study design. This type of methodology allows the in-depth investigation of contemporary events within their real-life contexts, without manipulation of relevant behaviours (Yin, 2009). Moreover, the usage of case study inquiry is recommended to 'enlighten those situations in which the intervention being evaluated has no clear, single set of outcomes'(Yin, 2009, p. 49). The selection of this methodology is further justified by the practical character of climate policies as well as the ICAT SD Guidance, both designed to be utilised in real-life settings.

Within the case study methodology, the ICAT SD Guidance will serve as a guide to identify the environmental, social, and economic impacts of the aforementioned climate policy. This tool provides steps in the form of key recommendations which will be followed in this thesis as well as a database with multiple methods, resources, and models for assessing specific impacts.

The identification of these specific impacts will follow a causal-chain approach and a life cycle thinking approach, both recommended by the ICAT SD Guidance. Whilst the former approach will help in identifying causal links between actions and impacts, the latter approach will help in identifying impacts ranging from the raw materials extraction of the technologies needed for the retrofits, all the way to the disposal of these technologies, both in-jurisdiction (state-wide) and out-of-jurisdiction (rest of the world). However, based on data availability, it is only within the environmental analysis that impacts will be assessed from the perspective of different life cycle phases. Thus, the social and economic assessment will only be performed from the point of view of the State of Jalisco.

Information from the case study needed for the assessments will be accessed in various ways: (i) energy bills; (ii) internal reports of the projects; (iii) management plans containing the projects; (iv) pictures from the site; (v) interviews with key actors involved in the policy design and implementation; and (vi) informal discussions with these informants.

The environmental assessment will be performed through an attributional Life Cycle Assessment (LCA) modelled in the SimaPro 8.5 software (Pré Consultants, 2018). The data for the LCA will be taken from the Ecoinvent v4.3 database (Wernet *et al.*, 2016). The social assessment will rely on administrative documentation related to the projects as well as interviews with stakeholders and informal discussions with these informants. Regarding the third dimension of sustainable development, the assessment will be divided into two major groups: socio-economic related impacts and impacts related to the cost-effectiveness of the selected policy.

1.4 Structure of the work

The remainder of this thesis is divided into five chapters. Chapter 2 presents climate policies, discusses several sustainable development impacts of climate policies, and introduces the concept of sustainable development impact assessment. Chapter 3 presents the methodology and methods used in this thesis to assess the policy impacts on each of the dimensions of sustainable development. Chapter 4 describes the Mexican climate policy case study and presents the assessment results. First, it introduces the climate policy and thereafter defines the system boundary of the study. Then, it summarises the results of the sustainable development impact assessment. Chapter 5 evaluates the results of the thesis and discusses the trade-offs and synergies of this policy as well as reflections on the process followed for impact identification. This chapter also provides suggestions for future research on how the results could be used in the policy design and implementation cycle. Finally, Chapter 6 presents the final conclusions of this work.

2 Climate policies and sustainable development impact assessments

Since this thesis aims to identify the sustainable development impacts of a specific climate policy, this chapter introduces climate policies, discusses several impacts climate policies have on sustainable development and presents the concept of sustainable development impact assessment for evaluating the aforementioned impacts. Section 2.1 provides general information about sustainable development and climate change. Section 2.2 introduces climate policies as instruments to mitigate climate change and presents existing types of climate policies. Section 2.3 summarises the linkages between sustainable development and climate change policies as well as reviews different types of impacts the latter can have on the former. Section 2.4 introduces different types of sustainable development assessments and describes in detail the tool used in this thesis.

2.1 Sustainable development and climate change

The most common starting point for those who set out to define sustainable development is the definition adopted by the World Commission on Environment and Development (WCED) published in a document known as the Brundlandt Report (WCED, 1987; Ness *et al.*, 2006). This somewhat standard definition states that sustainable development is the development that ‘meets the needs of the present without compromising the ability of future generations to meet their own needs’ (WCED, 1987). Therefore, the main concern of sustainable development is the ‘ability to maintain a coupled human–nature system at a desirable state for multiple generations in the face of anthropogenic and environmental perturbations and uncertainties’(Wu and Wu, 2012, p. 67).

The concept of sustainable development has not only been described as definitionally vague but essentially contested and political; where the widely accepted, yet ambiguous, general meaning of the concept can influence divergent and incompatible ways in which sustainable development is operationalized (Robinson and Herbert, 2001; Connelly, 2007). In this vein, Connelly (2017) presents three common ways of adopting the concept which include: (i) ignoring the complexities of the concept and presenting it as an unproblematic one; (ii) accepting the conceptual complexity of the term but selecting a “correct” interpretation of it; and (iii) making explicit the ambiguity. Furthermore, other criticisms and debates focus on considering the concept an oxymoron, challenging the inclusion of the commonly accepted three dimensions of sustainable development, questioning the equal value given to these dimensions, and viewing two of these three dimensions only as instruments necessary to achieve a goal within one main dimension (Giddings, Hopwood and O’Brien, 2002; Connelly, 2007; Lans, Blok and Wesselink, 2014; Sala, Ciuffo and Nijkamp, 2015). Thus, sustainable development remains a contested concept (Wilson and Piper, 2010; Lans, Blok and Wesselink, 2014). However, there is an increasing consensus that sustainable development is a process comprising environmental, social, and economic dimensions (Bond *et al.*, 2001). Taking into consideration these three dimensions uncovers issues related to pollution, biodiversity loss, resource depletion, environmental ethics, poverty, social justice, income inequalities, jobs, and wealth creation, among many others (Robinson and Herbert, 2001; Sathaye *et al.*, 2007).

Although climate change is an issue very closely linked to sustainable development, it is frequently treated separately (Robinson and Herbert, 2001). According to the UNFCCC, it refers to a 'change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods' (IPCC, 2007).

In this vein, the fifth assessment (AR5) of the Intergovernmental Panel on Climate Change (IPCC), one of the best well-known and highly supported scientific bodies working on analysing the causes and impacts of climate change, confirms that human activities are extremely likely (95%) to have been the dominant cause of many of the observed changes in the Earth's climate system. In addition, the report explains that the human activities causing this unprecedented increase in GHG emissions, leading to those changes, are strongly linked to economic and population growth, energy use, land use patterns, and lifestyles (IPCC, 2014). According to the IPCC (2014), 'continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems' (p. 56).

2.2 Climate policies

Tackling the foregoing effects of climate change is the ultimate goal of climate policies. Climate policies are top-down actions where climate change, in both its mitigation and adaptation efforts, is translated into an array of problems that will be differently defined and dealt within a system (Ahmad, 2009). On the one hand, mitigation refers to substantially and sustainably reducing the concentration of GHG in the atmosphere, thus, limiting the temperature increase (Morecroft and Cowan, 2010). Adaptation, on the other hand, refers to coping with the consequences of climate change, allowing human and natural systems to function effectively (Ibid.). However, the case study in this thesis focuses on climate change mitigation policies, which have commonly centred on the following six areas: (i) carbon conservation; (ii) carbon capture; (iii) energy conservation; (iv) energy efficiency; (v) renewable carbon-neutral power generation; and (vi) new green technologies (Wilson and Piper, 2010).

Regardless of the area a climate policy focuses on and depending on how climate change problems are dealt with, a climate policy may refer to different levels along a policy-making continuum such as (i) broad strategies defining high-level objectives; (ii) policy instruments to carry out a broad strategy; and (iii) the implementation of measures that result from the policy instruments (ICAT, 2017). The latter two levels can take multiple forms, which are presented in Table 1.

Table 1 Types of policies and actions. Source (ICAT, 2017, p.5), adapted from (WRI, 2014).

TYPE OF POLICY OR ACTION	DESCRIPTION
REGULATIONS AND STANDARDS	Regulations or standards that specify abatement technologies (technology standard) or minimum requirements for energy consumption, pollution output, or other activities (performance standard). They typically include penalties for noncompliance.
TAXES AND CHARGES	A levy imposed on each unit of activity by a source, such as a fuel tax, carbon tax, traffic congestion charge, or import or export tax.
SUBSIDIES AND INCENTIVES	Direct payments, tax reductions, price supports or the equivalent thereof from a government to an entity for implementing a practice or performing a specified action.
VOLUNTARY AGREEMENTS OR ACTIONS	An agreement, commitment or action is undertaken voluntarily by public or private sector actors, either unilaterally or jointly in a negotiated agreement. Some voluntary agreements include rewards or penalties associated with participating in the agreement or achieving the commitments.
INFORMATION INSTRUMENTS	Requirements for public disclosure of information. These include labeling programmes, reporting programmes, rating and certification systems, benchmarking, and information or education campaigns aimed at changing behaviour by increasing awareness.
EMISSIONS TRADING PROGRAMMES	A programme that establishes a limit on aggregate emissions of various pollutants from specified sources, requires sources to hold permits, allowances, or other units equal to their actual emissions and allows permits to be traded among sources. These programmes are also referred to as emissions trading systems (ETS) or cap-and-trade programmes.
RESEARCH, DEVELOPMENT, AND DEPLOYMENT (RD&D) POLICIES	Policies aimed at supporting technological advancement, through direct government funding or investment, or facilitation of investment, in technology research, development, demonstration, and deployment activities.
PUBLIC PROCUREMENT POLICIES	Policies requiring that specific attributes (such as social or environmental benefits) are considered as part of public procurement processes.
INFRASTRUCTURE PROGRAMMES	Provision of (or granting a government permit for) infrastructure, such as roads, water, urban services and high-speed rail.
IMPLEMENTATION OF NEW TECHNOLOGIES, PROCESSES OR PRACTICES	Implementation of new technologies, processes or practices at a broad scale (e.g., those that reduce emissions compared to existing technologies, processes or practices).
FINANCING AND INVESTMENT	Public or private sector grants or loans (e.g., those supporting development strategies or policies such as a development policy loans (DPL) or development policy operations (DPO) which includes loans, credits, and grants).

This multiplicity in the typology of climate policies has allowed governments all around the globe to adopt different types of policies, in accordance with their own resources or national strategies, whilst pursuing the goal of mitigating the effects of climate change. Furthermore, the increasing popularity of climate policies has been, in many cases, reinforced by the adoption of two global accords in 2015, namely the Paris Agreement and the SDGs.

The Paris Agreement was adopted by the 21st session of COP, under the UNFCCC (Uitto, Puri and van den Berg, 2017). The key target of this agreement is to keep, in this century, a global temperature rise below 2 degrees Celsius above pre-industrial levels, aiming for 1.5 degrees Celsius. This agreement also focuses on strengthening the ability of countries to cope with climate change impacts (UNFCCC, N.D.a).

With the Paris Agreement, countries representing over 95% of the global CO_2 emissions agreed to state their mitigation and adaptation goals through Nationally Determined Contributions (NDCs), which they are obliged to implement. They also agreed to a regular reporting of compliance, transparency in their implementation efforts and reports, and a periodic review and upgrade of the targets every 5 years (Weitzman, 2017).

In addition to the adoption of the Paris Agreement, 2015 was marked by the creation of the SDGs, which were set by the UN as a part of the 2030 Agenda for Sustainable Development. The aim of the SDGs is that of sharing a common vision towards a sustainable, just and safe space for human beings (Uitto, Puri and van den Berg, 2017). They came into force in January 2016 and were created as a follow up on the Millennium Development Goals (MDGs). The goals intend to 'mobilize efforts to fight inequalities, end all forms of poverty, tackle climate change, among others, while ensuring that no one is left behind and that every country has a common responsibility of delivering this vision' (United Nations, N.D.).

Whilst, the focus of the goals, as their name indicates, is on sustainable development, they also include multiple references to climate change. This can be observed in various targets belonging to 11 out of the 17 goals that include taking actions towards climate change. In addition, goal 13 'calls for urgent action to combat climate change and its impacts, recognizing the key linkages of climate change to development and human wellbeing' (Uitto, Puri & van den Berg, 2017, p.2).

2.3 Sustainable development impacts of climate policies

Although climate change is embedded in the interaction of larger environmental, social, and economic issues, which are the centre of sustainable development, literature and discourses on climate change and sustainable development have historically treated them independently (Robinson and Herbert, 2001). One of the reasons for this is that climate change has been commonly formulated as a natural science problem, ignoring its social and economic aspects, whilst sustainable development has been framed as a social science problem (Swart, Robinson and Cohen, 2003). This disconnection has led to a growing concern that by not acknowledging the axiomatic nature of sustainable development to climate change strategies, wider societal and environmental goals would be compromised (Morecroft and Cowan, 2010).

Linkages between sustainable development and climate change have been moderately explored (Sathaye *et al.*, 2007; Pinkse and Kolk, 2012; Harry and Morad, 2013; IPCC, 2014). These studies have looked at the relationships between the two concepts in a developing country context and how climate change strategies require the broader scope of sustainable development in order to be effective.

Swart, Robinson & Cohen (2003) suggest other linkages between climate change and sustainable development in the area of policies, which are shown in Figure 1. In summary, climate policies can affect sustainable development objectives in the following ways: (i) reducing climate change damages coming from GHG emissions and the vulnerability to climate-related hazards; (ii) providing ancillary benefits; (iii) causing positive and negative spillover effects on other countries; as well as (iv) inducing and spreading environmentally sound technological innovations committed to reducing GHG emissions. On the other hand, sustainable development policies can affect climate change by: (i) pursuing alternative development pathways, especially low-carbon ones; (ii) supporting specific sectoral policies with evident climate side effects; (iii) pursuing institutional changes; and (iv) stimulating technological innovation and changes in environmentally sound directions.

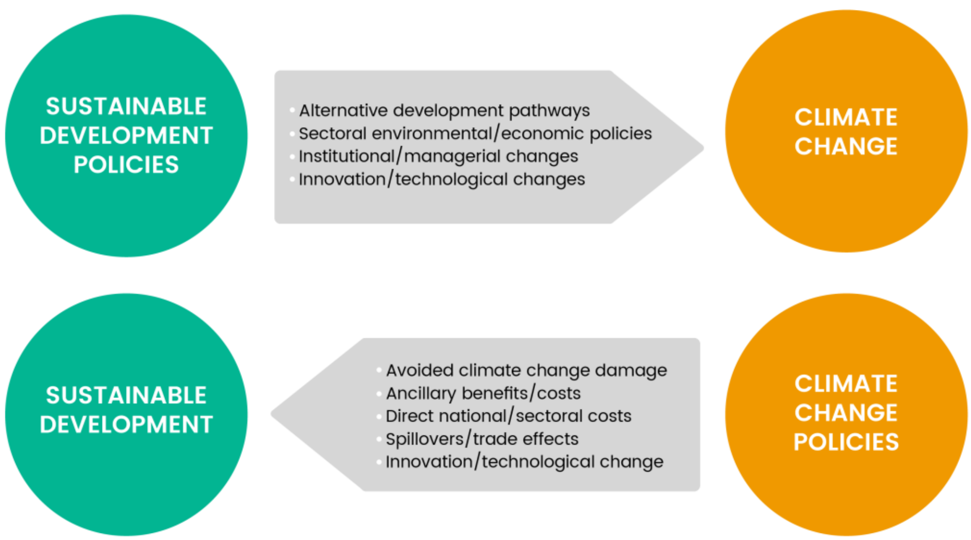

Figure 1 Linkages between sustainable development, climate change, and policies in these areas. Adapted from (Swart, Robinson and Cohen, 2003, p. S21).

The strong linkages between climate change and sustainable development make each of them susceptible to changes caused by the other. The changes in one area, as a result of actions pursued in the other area, are known as impacts. In the context of sustainable development, impacts from climate policies, or any type of policy, can take the following form: (i) positive and negative impacts; (ii) intended and unintended impacts; (iii) short-term and long-term impacts; (iv) in-jurisdiction and out-of-jurisdiction impacts; (v) technology impacts; (vi) business and consumer impacts; (vii) infrastructure impacts; (viii) market impacts; (ix) life cycle impacts; (x) macroeconomic impacts; (xi) trade impacts; (xii) institutional impacts; and (xiii) distributional impacts (WRI, 2014; ICAT, 2017). Table 2 describes each of the types of impacts a climate policy can have on sustainable development.

Although Table 2 is a comprehensive list of types of potential impacts, it remains as a non-exhaustive list with non-mutually exclusive types of impacts. For example, whilst a climate policy might have a positive, long-term and in-jurisdiction impact, another policy might have a negative, short-term and unintended impact.

Table 2 Types of impacts and definitions. Source (ICAT, 2017, p. 68), adapted from (WRI, 2014).

TYPE OF IMPACTS	DEFINITION
POSITIVE AND NEGATIVE IMPACTS	Impacts that are perceived as favourable or unfavourable from the perspectives of different stakeholder groups.
INTENDED AND UNINTENDED IMPACTS	Impacts that are intentional or unintentional, based on the original objectives of the policy or action and from the perspective of policymakers and stakeholders. (In some contexts, intentional impacts are called primary impacts and unintended impacts are called secondary impacts.)
SHORT-TERM AND LONG-TERM IMPACTS	Impacts that are nearer or more distant in time, based on the amount of time between implementation of the policy and the impact.
IN-JURISDICTION AND OUT-OF-JURISDICTION IMPACTS	Impacts that occur inside the geopolitical boundary over which the implementing entity has authority, such as a city boundary or national boundary, as well as impacts that occur outside of the geopolitical boundary.
TECHNOLOGY IMPACTS	Changes in technology such as design or deployment of new technologies
BUSINESS AND CONSUMER IMPACTS	Changes of business practices or behaviour (such as manufacturing decisions) or consumer practices or behaviour (such as purchasing decisions)
INFRASTRUCTURE IMPACTS	Changes in existing infrastructure or development of new infrastructure.
MARKET IMPACTS	Changes in supply and demand, prices, market structure or market share.
LIFE CYCLE IMPACTS	Changes in upstream and downstream activities, such as extraction and production of energy and materials, or impacts in sectors not targeted by the policy or action.
MACROECONOMIC IMPACTS	Changes in macroeconomic conditions, such as GDP, income, employment, or structural changes in economic sectors.
TRADE IMPACTS	Changes in imports and exports.
INSTITUTIONAL IMPACTS	Changes in institutional arrangements.
DISTRIBUTIONAL IMPACTS	Changes in how income, resources or costs are distributed among a population, or changes among different demographic groups, such as gender or income groups.

2.4 Types of sustainable development impact assessments

The adoption of climate policies has posed important challenges to governments and organisations all around the world when determining the sustainable development impacts of these policies. Therefore, sustainability or sustainable development assessment, as an integrated analysis of the environmental, social, and economic impacts of an intervention, has become a rapidly developing area (Bond *et al.*, 2001; Ness *et al.*, 2006).

According to Uitto, Puri and van den Berg (2017), sustainability assessments can take different forms based on their objectives. They can be summative, prospective, or formative, depending if the focus is on determining whether the intervention has achieved the results anticipated, on looking at the possible outcomes of the interventions *a priori*, or on analysing how an intervention is implemented in order to be improved.

The increasing variety of approaches used in assessing the environmental, social, and economic effects of an intervention, can also be categorised according to their hierarchical relationships and the scope of the analysis. Figure 2 presents the terminology and hierarchical relation adopted in this thesis based on the work of Zijp *et al.* (2015) as well as Sala, Farioli, and Zamagni (2013).

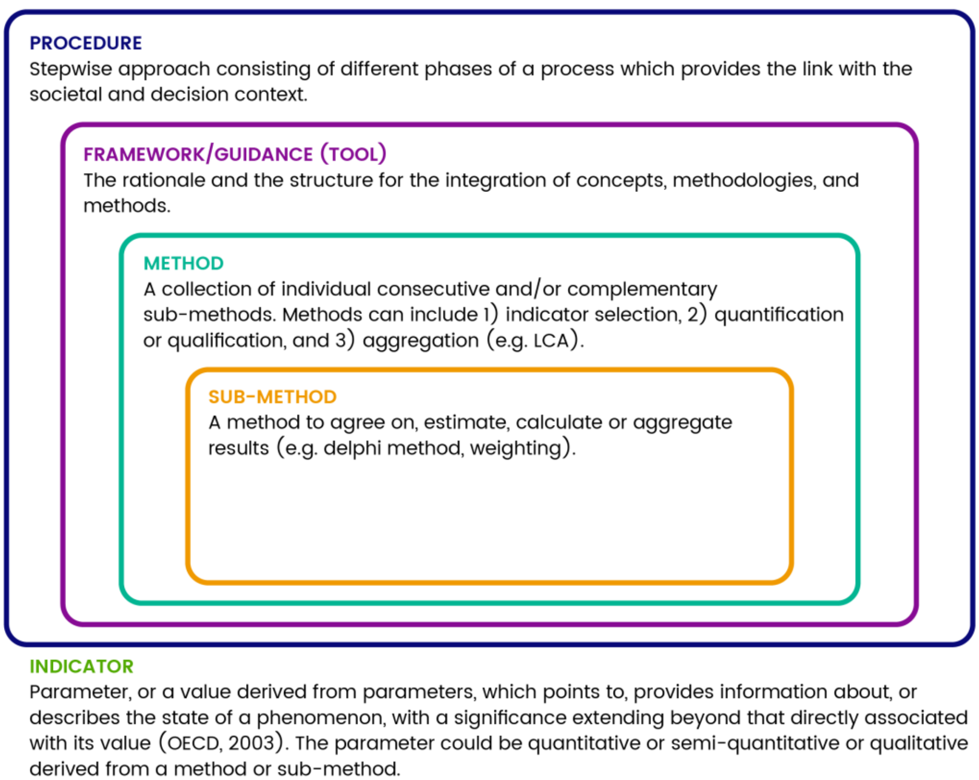

Figure 2 Terminology and their hierarchical relation adopted in this thesis. Adapted from (Zijp et al., 2015; Sala, Farioli and Zamagni, 2013).

Based on the terminology presented in Figure 2, the type of sustainable impact assessment selected for this thesis, the ICAT SD Guidance, falls into the category of framework and guidance (tool). This tool was developed by the Initiative for Climate Action Transparency (ICAT), which is an initiative created to support transparency and capacity building under the Paris Agreement and the SDGs (ICAT, N.D.a.). Among the main projects of the initiative is the ICAT Series of Guidance. This series consists of core and complementary guidance following a modular structure that were developed to support the assessment of sustainable development, transformational change, and GHG emissions reduction of climate actions and policies (ICAT, N.D.b).

Specifically, the ICAT SD Guidance has the purpose to assess qualitatively and quantitatively the sustainable development impacts of policies and actions in an integrated manner in order to support policymakers and other decision-makers (Ibid.). This tool provides guidance applicable to all types of policies and actions as well as assesses all types of sustainable development impacts. Further explaining its applicability, the guidance can be used to assess policies and actions at any governmental level, in any sector, and at any stage in the policy design and implementation cycle. Therefore, an ex-ante (forward looking), an ex-post (backward looking) or a combination of both assessments can be done depending on the policy or action (Ibid.)

In terms of types of interventions along the policy-making continuum, the tool is only applicable to ‘policy instruments and implementation of technologies, processes or practices’ (ICAT, 2017, p.7). It is not advisable to use it on higher level types of interventions such as broad strategies or plans since the tool requires a rather great amount of detail and information to assess the impacts (ICAT, 2017). The first draft of the ICAT SD Guidance was released in 2017. A second draft and a final document are expected to be released in 2018 and 2019, respectively. Therefore, there are currently no reports on how the tool has been used to assess sustainable development impacts.

The ICAT SD Guidance was developed by building upon the following existing tools to evaluate the sustainable development impacts of climate policies: (i) the NAMA Sustainable Development Evaluation Tool; (ii) the Framework for Measuring Sustainable Development in NAMAs; (iii) the CDM Sustainable Development Tool; and (iv) the GHG Protocol Policy and Action. All of these tools have some sort of linkages between climate policies and sustainable development, all of them are considered climate-first approaches since the main focus of the policy is the mitigation of GHG emissions. Additionally, all are theme-based frameworks, organising indicators around key issues and all are available to the public online.

3 Research design and methods

The previous chapter presented climate policies, discussed types of sustainable development impacts of the aforementioned policies, and presented the concept of sustainable development impact assessment for evaluating the aforementioned impacts.

Using the ICAT SD Guidance as a tool within the case study methodology, this chapter presents the steps and methods used in this thesis to assess the policy impacts on each of the dimensions of sustainable development. Section 3.1 introduces the case study methodology at a high-level, presents the research design followed in this thesis as well as describes the data collection process. Section 3.2 presents an overview of the steps followed for the case study assessment, given by the ICAT SD Guidance. Sections 3.3, 3.4, and 3.5 describe the methods for assessing the data used in the environmental, social, and economic assessments, respectively.

3.1 Case study methodology

Yin (2009) defines a case study as a methodology used to perform an in-depth analysis of contemporary phenomena within their real-life contexts. Furthermore, the case study is not only capable of dealing with situations where there exist more variables compared to data points but it also relies on multiple sources of data. There are several applications for the case study, depending on the type of questions to be answered with this methodology. Thus, a case study can be explanatory, descriptive or exploratory.

In order to achieve the aim of this thesis, an exploratory case study methodology was selected to guide the research design and data collection of the present study. The main application of an exploratory case study is ‘to enlighten those situations in which the intervention being evaluated has no clear, single set of outcomes’(Yin, 2009, p. 49). This application caters to the needs of the present assessment where determining the sustainable development impacts of a climate intervention is a complex and case-specific task.

3.1.1 Research design

An embedded single-case study design was selected to structure the analysis of this thesis. Following Yin’s (2009) rationales for the selection of case study types, a single-case study was deemed appropriate based on the level of popularity and representativeness of the selected climate policy in the context it was implemented (i.e. Mexico and public buildings).

In an embedded single-case study, different units of analysis exist within the case and each of the units can be subject of data collection and analysis through a wide variety of methods. It should be noted that the case study in this thesis consists of two different climate actions, which are not considered different cases. This decision was based on the interrelationships of the climate actions which were also geographically bounded to a common space during their use phase. For the purpose of this thesis, each of the two selected actions represents a different unit of analysis. Within these units, each dimension of sustainable development represents a different sub-unit of analysis. Figure 3 illustrates how the specific case fits in the context as well as how the units and sub-units of analysis constitute the specific case.

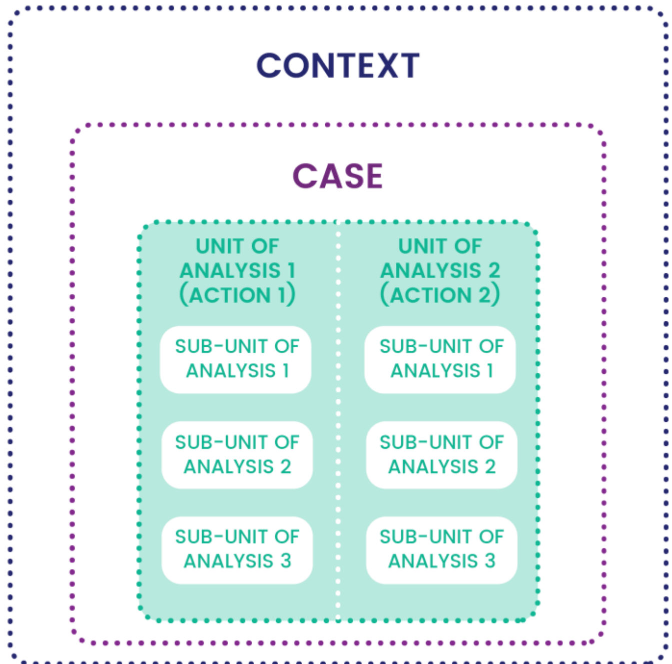

Figure 3 Embedded single-case study design. Adapted from (Yin, 2009).

3.1.2 Data collection

Commonly, there are six sources of data used in case studies: (i) documents; (ii) archival records; (iii) interviews; (iv) direct observation; (v) participant observation; and (vi) physical artifacts (Yin, 2009). For the purpose of this case study, three out of six sources were used, namely, documents, archival records, and interviews. Additionally, multiple peer-reviewed articles and books supported the case study assessment. Data from these sources was compiled through an extensive desktop study, using online search engines such as ScienceDirect, Mendeley, and Google Scholar as well as using various search strings (e.g. "sustainability assessment of PV panels", "environmental assessment of PV panels", "social assessment of PV panels", "economic assessment of PV panels", "LCA of luminaires", "sustainable impact assessment of building retrofits").

In addition to the extensive analysis of peer-reviewed articles and books, administrative documents were analysed. These documents consisted of progress reports and internal records shared by the Ministry of Environment and Territorial Development (SEMADET) of the State of Jalisco and Carbon Trust Mexico. However, based on project confidentiality, the original material is not presented in this thesis. Nevertheless, data used to perform the assessments, in addition to assumptions and uncertainties related to these calculations are presented in Chapter 4.

In regard to interviews, several online semi-structured interviews were performed at different stages of the assessment between March 2018 and June 2018. This type of interviews allowed the interviewer to formulate questions related to a specific topic without limiting interviewee answers (Eriksson & Kovalainen, 2008). Furthermore, semi-structured interviews allowed the introduction of follow-up questions specific to the type of stakeholder interviewed. The interview protocols, presented in Appendices 3 to 5, consisted of open-ended questions as well as a few follow-up questions depending on the role of the stakeholder. It should be noted that all the interviews were online, given that key stakeholders were located in Mexico. The average duration of the interviews was one and a half hours and they were all conducted in Spanish. Thus, all interviews were transcribed in Spanish and they are not included in this thesis. However, the transcripts were used for data analysis. After each interview, a summary was shared with each stakeholder giving them the opportunity to clarify or build upon their answers. All transcriptions were then cross-referenced with personal notes taken during the interviews.

Table 3 summarises the main interviews organised by the role of the stakeholder, the stage in the process the interview was performed according to the ICAT SD Guidance, and the type of interview. This guidance defines specific stages where the involvement of relevant stakeholders and expert opinion are needed to make the impact assessment a comprehensive and holistic one. Throughout the process of this thesis, other communication channels were used to contact experts and gain access to the data needed for the assessments. However, Table 3 does not include them, since they did not follow a specific protocol.

Table 3 Interviewed stakeholders.

STAKEHOLDER(S)	STAGE	TYPE OF INTERVIEW	INTERVIEW PROTOCOL
AREA COORDINATOR (1) & DIRECTOR (2) - TRANSVERSAL MANAGEMENT DIRECTION FOR CLIMATE CHANGE IN THE MINISTRY OF ENVIRONMENT AND TERRITORIAL DEVELOPMENT (SEMADET)	IMPACT CATEGORIES SELECTION	ONLINE SEMI-STRUCTURED INTERVIEW	YES (APPENDIX 3)
	QUALITATIVE ASSESSMENT	ONLINE SEMI-STRUCTURED INTERVIEW	YES (APPENDIX 4)
ASSOCIATE - CARBON TRUST (ENERGY EFFICIENCY SPECIALIST)	IMPACT CATEGORIES SELECTION	ONLINE SEMI-STRUCTURED INTERVIEW	YES (APPENDIX 3)
	QUALITATIVE ASSESSMENT[1]	ONLINE SEMI-STRUCTURED INTERVIEW	NO
PV PANEL SUPPLIER	IMPACT CATEGORIES SELECTION	ONLINE SEMI-STRUCTURED INTERVIEW	YES (APPENDIX 3)
	QUALITATIVE ECONOMIC ASSESSMENT	E-MAIL INTERVIEW	NO
GENERAL SERVICES DIRECTOR – MINISTRY OF PLANNING, ADMINISTRATION, AND FINANCE (SEPAF)	IMPACT CATEGORIES SELECTION	ONLINE SEMI-STRUCTURED INTERVIEW	YES (APPENDIX 3)
	QUALITATIVE SOCIAL ASSESSMENT	ONLINE SEMI-STRUCTURED INTERVIEW	YES (APPENDIX 5)

[1] Not a whole interview focused on this stage, but input and material shared for the qualitative assessment.

As previously mentioned, the embedded single-case study design allows the incorporation of multiple methods to assess each unit of analysis. Therefore, the following sections present the steps followed from the ICAT SD guidance as well as the methods used to determine the environmental, social, and economic impacts of the selected climate policy.

3.2 ICAT SD Guidance process overview

3.2.1 Sustainable development impacts identification

In order to identify the impacts of the selected climate policy in the case study, the general steps and key recommendations from the ICAT SD Guidance were followed. Paralelly, a high-level comparison of the four tools mentioned in Section 2.4 was performed in order to complement specific stages of the assessment, when those stages were not covered by ICAT. This comparison can be found in the Appendix 1. Once the policy to be assessed was determined, impact categories within each dimension of sustainable development were identified. In order to define these impact categories, the ICAT SD Guidance provides a non-exhaustive list of potential impacts. Added to those recommendations, impact categories were identified following a combination of methods. These methods included a review of predefined impact categories from the sustainable development tools introduced in Section 2.4, an analysis of practical examples from climate policies which have been subject to analysis under these four tools, literature review of prior assessments done to similar policies, and recommendations from interviewed key stakeholders. Details of these interviews including the interview protocol are found in Appendix 3. After the impact categories identification, the latter were analysed based on their significance, relevance, and comprehensiveness.

Following ICAT (2017) recommendations, this analysis was achieved in conjunction with the foregoing stakeholders. First, the significance of each impact category was determined, followed by the relevance, and finally the comprehensiveness. Whilst significance is a criterion used to select impact categories that are considerably influenced by the policy, relevance is a more subjective criterion that analyses how pertinent the impact category is to a specific stakeholder, goal, or the objectives of the assessment. Additionally, comprehensiveness is understood as an overarching criterion that aims to ensure the thoroughness and balance of the study in regard to the three dimensions of sustainable development (Ibid.). Table 4 presents all impact categories taken into consideration in the case study as well as their evaluation based on significance, relevance, and comprehensiveness. A detailed process of this impact category identification is included in Chapter 4 (Tables 9 to 13).

Table 4 Summary of impact categories evaluated based on their significance, relevance, and comprehensiveness.

ENVIRONMENTAL IMPACT CATEGORIES	SIGNIFICANT, RELEVANT, & COMPREHENSIVE	SOCIAL IMPACT CATEGORIES	SIGNIFICANT, RELEVANT, & COMPREHENSIVE	ECONOMIC IMPACT CATEGORIES	SIGNIFICANT, RELEVANT, & COMPREHENSIVE
GHG EMISSIONS	**YES**	HEALTH AND SAFETY OCCUPATIONAL RISKS	**YES**	JOBS	**YES**
OZONE DEPLETION	**NO**	WAGES	**NO**	INCOME GENERATION	**NO**
AIR QUALITY	**YES**	WORKING HOURS	**NO**	LOCAL ECONOMY	**YES**
OZONE FORMATION	**NO**	DISCRIMINATION	**NO**	LIFE CYCLE COSTS	**NO**
TOXIC CHEMICALS RELEASED TO AIR	**NO**	FORCED LABOUR	**NO**	POLICY IMPLEMENTATION COSTS	**YES**
FRESHWATER CONSUMPTION	**YES**	CHILD LABOUR	**NO**	POLICY COST-EFFECTIVENESS	**YES**
WATER QUALITY	**NO**	TRAINING	**YES**	COST SAVINGS	**YES**
BIODIVERSITY OF WATER ECOSYSTEMS	**NO**	CLIMATE CHANGE AWARENESS	**YES**	PAYBACK PERIOD	**YES**
TOXIC CHEMICALS RELEASED TO WATER	**YES**	PUBLIC IMAGE	**NO**	ENERGY INDEPENDENCE	**NO**
LAND USE	**YES**	LOCAL R&D	**YES**	ENERGY DIVERSIFICATION	**NO**
SOIL QUALITY	**NO**	PUBLIC ACCEPTANCE OF RENEWABLES	**YES**	SUPPORTING INFRASTRUCTURE	**NO**
BIODIVERSITY OF TERRESTRIAL ECOS.	**NO**	HUMAN HEALTH (USE PHASE)	**YES**	REBOUND EFFECTS	**YES**
MINERAL RESOURCES DEPLETION	**YES**				
FOSSIL RESOURCES DEPLETION	**YES**				
RENEWABLE ENERGY GENERATION	**YES**				
RENEWABLE ENERGY SHARE	**YES**				
WASTE GENERATION AND DISPOSAL	**YES**				

Then, each selected impact category was further analysed to identify the specific changes the policy or action causes. These changes are called specific impacts and they were identified using a series of causal chain diagrams. Causal chains are conceptual diagrams that establish relationships of causation between variables (Delgado-Maciel *et al.*, 2018). These causal chain diagrams are presented in Chapter 4 (Figures 9 to 11). The specific impacts were then analysed in the qualitative assessment based on the likelihood the impact would occur, the expected magnitude of the change, and the nature of it. Tables 5 and 6 present the guidelines used to determine the likelihood and magnitude of each specific impact within the qualitative assessment, based on the ICAT SD Guidance. The significance of these two criteria was then assessed following recommendations presented in Figure 4.

Similar to the impact categories selection, the qualitative assessment was completed with the involvement of civil servants from SEMADET as well as relevant data from peer-reviewed articles and reports from several international organisations. Details of these interviews including the interview protocol are found in Appendix 4.

<table>
<tr><th>LIKELIHOOD</th><th colspan="3">MAGNITUDE</th></tr>
<tr><td>VERY LIKELY</td><td>MINOR</td><td>MODERATE</td><td>MAJOR</td></tr>
<tr><td>LIKELIHOOD</td><td rowspan="4">INSIGNIFICANT</td><td colspan="2" rowspan="2">SIGNIFICANT</td></tr>
<tr><td>POSSIBLE</td></tr>
<tr><td>UNLIKELY</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>VERY UNLIKELY</td></tr>
</table>

Figure 4 Recommended approach for determining significance based on likelihood and magnitude. Source (ICAT, 2017, p.74), adapted from (WRI, 2014).

Table 5 Assessing the likelihood of sustainable development impacts. Source (ICAT, 2017, p.71), adapted from (WRI, 2014).

LIKELIHOOD	DESCRIPTION	APPROXIMATE LIKELIHOOD
VERY LIKELY	Reason to believe the impact will happen (or did happen) as a result of the policy or action.	≥ 90%
LIKELY	Reason to believe the impact will probably happen (or probably happened) as a result of the policy or action.	<90% and ≥ 66%
POSSIBLE	Reason to believe the impact may or may not happen (or may not have happened) as a result of the policy or action.	<66% and ≥ 33%
UNLIKELY	Reason to believe the impact probably will not happen (or probably did not happen) as a result of the policy or action.	< 33% and ≥ 10%
VERY UNLIKELY	Reason to believe the impact will not happen (or did not happen) as a result of the policy or action.	< 10%

Table 6 Estimating the relative magnitude of sustainable development impacts. Source (ICAT, 2017, p.72), adapted from (WRI, 2014).

RELATIVE MAGNITUDE	DESCRIPTION
MAJOR	The change in the impact category is (or is expected to be) substantial in size.[2] The impact significantly influences the effectiveness of the policy or action with respect to that impact category.
MODERATE	The change in the impact category is (or is expected to be) moderate in size.[2] The impact significantly somewhat influences the effectiveness of the policy or action with respect to that impact category.
MINOR	The change in the impact category is (or is expected to be) moderate in size.[2] The impact is inconsequential to the effectiveness of the policy or action with respect to that impact category.

[2] The magnitude of the change should be considered relative to the broader conditions related to the impact category or to the maximum potential impact from policy options considered feasible.

Table 7 presents a high-level summary of the specific impacts included in the qualitative assessment and their analysis based on significance (likelihood and magnitude). The detailed process followed in the qualitative assessment can be found in Chapter 4 (Tables 17 and 25).

Table 7 Summary of specific impacts evaluated based on their significance in the qualitative assessment. Specific impacts coloured in red were further assessed quantitatively.

ENVIRONMENTAL SPECIFIC IMPACTS	SIGNIFICANT	SOCIAL SPECIFIC IMPACTS	SIGNIFICANT	ECONOMIC SPECIFIC IMPACTS	SIGNIFICANT
GHG EMISSIONS	**YES**	HEALTH AND SAFETY OCCUPATIONAL RISKS	**NO**	JOBS	**YES**
AIR QUALITY	**YES**	TRAINING	**NO**	POLICY IMPLEMENTATION COSTS	**YES**
HUMAN TOXICITY	**YES**	CLIMATE CHANGE AWARENESS	**YES**	POLICY COST-EFFECTIVENESS	**YES**
FRESHWATER CONSUMPTION	**YES**	LOCAL R&D	**NO**	COST SAVINGS	**YES**
LAND USE	**YES**	PUBLIC ACCEPTANCE OF RENEWABLES	**YES**	PAYBACK PERIOD	**YES**
MINERAL RESOURCES DEPLETION	**YES**	HUMAN HEALTH (USE PHASE)	**YES**	REBOUND EFFECTS	**YES**
FOSSIL RESOURCES DEPLETION	**YES**				
WASTE GENERATION AND DISPOSAL	**YES**				
RENEWABLE ENERGY GENERATION	**YES**				
RENEWABLE ENERGY SHARE	**YES**				

Using the results from the qualitative assessment, 13 specific impacts that were deemed significant and feasible to quantify were selected to be further analysed in the quantitative assessment (highlighted in red in Table 7). In this assessment, adequate indicators were defined based on peer-reviewed articles and existing reports. Furthermore, a baseline scenario and a policy scenario were estimated for each indicator, allowing the net impact calculation of each specific impact, as the measurable difference between the two scenarios. Data used to estimate these scenarios in addition to the assumptions and uncertainties related to these calculations are presented in Sections 4.4 and 4.5. Figure 5 presents an overview of the steps previously described as well as the criteria used in each step to analyse the impacts.

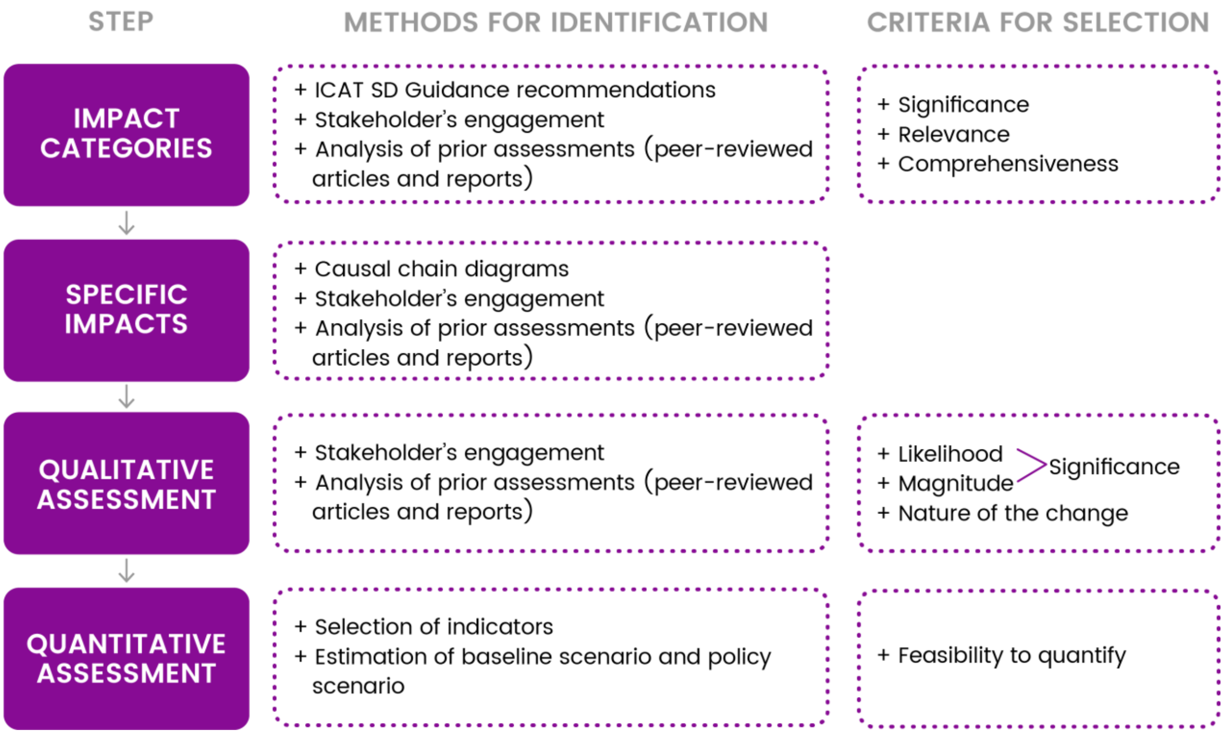

Figure 5 Overview of sustainable development dimensions, impact categories, specific impacts, indicators, and parameters. Adapted from (ICAT, 2017).

3.3 Assessing environmental impacts

3.3.1 Life Cycle Assessment

In order to determine the majority of the environmental impacts, a Life Cycle Assessment (LCA) was completed, using SimaPro (Pré Consultants, 2018) as the LCA software with access to the Ecoinvent v3.4 database (Wernet *et al.*, 2016). As presented in sub-section 3.1.2, data from the case study needed for the LCA was accessed in various ways: (i) energy bills; (ii) internal reports of the project; (iii) management plans containing the projects; (iv) pictures from the site; and (v) interviews with the main supplier. Based on project confidentiality, the original material is not presented in this thesis, however, data used to perform the LCA, in addition to assumptions and uncertainties related to these calculations are presented in Sections 4.4 and 4.5.

LCA is a method to systematically assess the potential impacts on the environment of a product, process, service or activity over its life cycle (Tähkämö, 2013; Hauschild and Huijbregts, 2015). It is an iterative method which relies on the usage of a functional unit as a 'quantified description of the service provided by the product system' (Curran, 2015, p.24). The functional unit serves as the basis to which the assessment is proportionated in order to be quantified (Tähkämö, 2013).

The current LCA methodology includes the 'process of compiling and evaluating the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle' (Curran, 2015, p.12). Figure 6 presents the four main phases, recognised by the International Standards Organisation (ISO) in the 14040 series developed for LCA. These phases include

(i) goal and scope definition; (ii) inventory; (iii) impact assessment; and (iv) interpretation. These four main phases were followed to determine the environmental impacts of each selected specific impact.

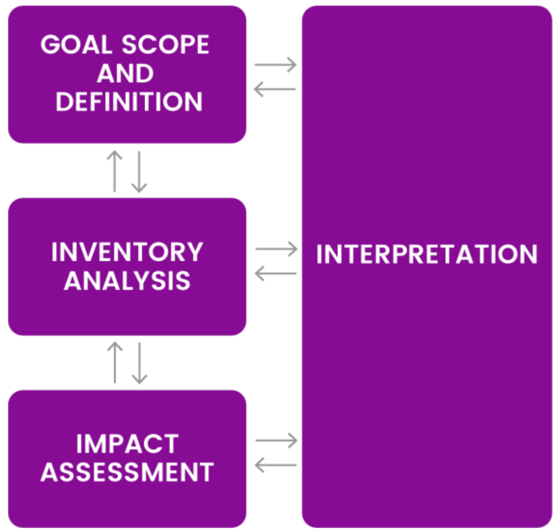

Figure 6 Main phases of an LCA (ISO 14040:2006, 2006).

First, the functional unit, system boundaries, and assumptions were defined within the goal and scope definition. Then, during the Life Cycle Inventory (LCI) phase, energy usage and raw material inputs associated with every stage of the product-system life cycle were quantified. In the third stage, the Life Cycle Inventory Analysis (LCIA) was conducted. It was in this stage where potential impacts on the environment and humans were associated with the results from the LCI. The LCIA was done following two main approaches, depending on the specific impact assessed, midpoint (problem-oriented approach) and endpoint (damage approach). Whilst the latter approach leads to an easier interpretation based on its closeness to the areas of protection, the former has a greater relation to elementary flows as well as a lower model uncertainty (Hauschild and Huijbregts, 2015). Last, the interpretation stage included the analysis of the results and sensitivity analyses, presented in sub-sections 4.4.5 and 4.5.5 (Tähkämö, 2013; Hauschild and Huijbregts, 2015).

3.3.2 Other specific impacts

Other specific impacts included in the environmental assessment were related to renewable energy generation in the assessed period. In this case, indicators were estimated using the data described in the previous sub-section. However, conducting an LCA was not required. Nevertheless, all environmental specific impacts considered significant in the qualitative assessment were measured.

3.4 Assessing social impacts

In-jurisdiction social impacts were assessed through the analysis of administrative documentation, mostly progress reports, concerning social awareness and social acceptance of energy efficiency and renewable energy technologies, peer-reviewed articles concerning health impacts of lighting as well as through semi-structured interviews with the General Services Director from the retrofitted building and with staff from the Ministry of Environment and Territorial Development (SEMADET). Details of the interviews, including the interview protocol, are presented in Appendix 5.

Furthermore, public (socio-political) acceptance is assessed in this social dimension, utilising Rogers (2005) model for "Innovation-Decision Process". In this model, social acceptance is defined as the use or adoption of a technology which follows five stages: (i) knowledge; (ii) persuasion; (iii) decision; (iv) implementation; and (v) confirmation (Rogers, 2003; Mallett, 2007). During the first stage, the stakeholder becomes aware of the project (technology or innovation). In the second phase, the stakeholder assesses the costs and benefits of the project and forms a positive or negative attitude towards it. During the decision stage the project is accepted or rejected; if accepted, it is put into use in the implementation phase. Finally, the decision to continue using the innovation or technology (project) is made in the fifth stage (Rogers, 2005).

3.5 Assessing economic impacts

The economic impact assessment was divided in two major groups of impact categories, each of these groups required a different type of assessment. On the one hand, impact categories related to costs and cost savings were assessed quantitatively, on the other hand, socio-economic impacts were assessed qualitatively.

Information from the case study needed for the economic assessment was accessed in various ways: (i) energy bills; (ii) internal reports of the project; (iii) management plans containing the projects; (iv) pictures from the site; and (v) interviews with the main supplier. Similar to the data used for the LCA, the original material is not presented in this thesis, however, data used to perform the assessment, in addition to assumptions related to these calculations are presented in Sections 4.4 and 4.5.

In order to qualitatively assess the socio-economic impacts, an interview with the photovoltaic (PV) panels supplier was conducted. This was supplemented with an analysis of the procurement act regulating the region assessed, in addition to non-geographically specific analysis of peer-reviewed articles on the subject.

The specific impacts related to costs and cost savings were quantitatively assessed following one of the most commonly used indicators for assessing energy investments in buildings and their profitability, cost payback time (Christersson, Vimpari and Junnila, 2015; Tse, Chow and Su, 2016). Another common indicator aiming to analyse the profitability of the project, Net Present Value (NPV), was also included in the assessment.

Simple payback time (SPB) is the time needed to recover the investment costs (Yang and Yu, 2015). This indicator was calculated by dividing the investment costs I_t by the annual gross electricity savings BR_t, as can be seen in Eq. 1 (Yang and Yu, 2015). In the case study, data required to determine SPB was calculated as follows: (i) investment costs, which happened at the beginning of year 1, were found in internal project reports and validated with key governmental stakeholders; (ii) electricity savings from year 1 (i.e. 2014), adjusted to 12 months instead of nine, were also found in internal project reports and are based on the actual electricity tariff applicable to the year in which the investment was made (i.e. 2014), retrieved from the Mexican Energy Information System (*Sistema de Información Energética*) (SIE in Spanish), which is maintained by the Ministry of Energy (*Secretaría de Energía*) (SENER in Spanish). Thus, no uncertainty is related to this calculation.

$$SPB = \frac{I_t}{BR_t} \tag{1}$$

NPV is considered a 'significant driver of overall cost-effectiveness analysis of energy efficiency' (Yang and Yu, 2015, p. 68). Furthermore, it is used to assess the profitability of a specific project based on the difference between the discounted and accumulated benefits (cash inflows) of a project compared to the discounted and accumulated costs (cash outflows) of it (Yang and Yu, 2015). NPV was calculated by subtracting the present value of project costs (C) from the present value of project benefits (B) as shown in Eq. 2 (Yang and Yu, 2015). Equations 3 and 4 (Ibid.), present in a detailed manner the calculations needed to determine B and C.

$$NPV = B - C \tag{2}$$

$$B = \sum_{t=1}^{n} \frac{BR_t + TC_t + INC_t + AB_{at} + PA_{at} + OB_t}{(1+d)^{t-1}} \tag{3}$$

$$C = \sum_{t=1}^{n} I_t + \frac{PC_t + BI_t + OC_t}{(1+d)^{t-1}} \tag{4}$$

In Eq. 3, *B* represents the present value of benefits, BR_t the annual gross electricity savings, TC_t the annual tax credits, INC_t the annual incentives paid by the government, AB_{at} the annual avoided bill from the alternate fuel(s), PA_{at} the annual avoided costs from alternate fuel devices or infrastructure, OB_t other annual financial benefits, *d* the discount rate of the project, and *n* the economic lifetime of the project in years.

In Eq. 4, *C* represents the present value of project costs, where I_t equals the capital investment in year t, which in the context of the case study it is only calculated at the beginning of year 1; PC_t the operation and maintenance costs; BI_t the energy bill increases in year t; and OC_t represents any other costs in the selected year.

As further explained in Sections 4.4 and 4.5, in Eq. 4, no tax credits, incentives, avoided costs from alternate fuel devices, nor other financial benefits were applicable to the case study. Thus, the present value of benefits (B) calculation only relied on the annual gross electricity savings, the annual avoided bill from the alternate fuels as well as the selected discount rate. Similarly, in the present value of costs (C), the calculation only relied on the capital investments, since no other costs were applicable to the case study. Furthermore, the capital investments only happened once at the beginning of year 1.

Since the annual gross electricity savings were retrieved from governmental reports and validated with stakeholders, no uncertainty exists for this figure. However, in order to calculate the annual avoided bill from the alternate fuel, an annual 3% actual increase of electricity prices was assumed, based on an electricity sector price analysis from the Ministry of Energy (SENER) (SENER, 2017). Furthermore, the real social discount rate of the project was assumed to be 3.3%, based on an analysis from the World Bank on Latin American economies and investments from the public sector (Lopez, 2008). However, several sensitivity analyses concerning the selection of real discount rate and actual electricity price increase rate are performed in sub-sections 4.4.5 and 4.5.5 in order to manage uncertainty in the rate selection. The rates used in these sensitivity analyses were selected based on reports retrieved from the Ministry of Environment and Territorial Development (SEMADET) and Carbon Trust Mexico; which were involved in the analysis of energy efficiency projects throughout the State of Jalisco and which considered the country's political situation.

Based on the relevance to key stakeholders and the climate change legal instruments preceding the case study, the policy cost-effectiveness was also included in the economic impact assessment. The cost-effectiveness analysis was used to 'determine the ratio of costs to effectiveness for a given impact category' (ICAT, 2017, p. 41). In the case study, only climate change mitigation was analysed using this indicator, since the primary objective of the action is GHG emissions reduction. Cost-effectiveness was calculated following Eq. 5, dividing the investment costs by the total tCO_2 eq mitigated per policy represented as CM_t.

$$Cost\ effectiveness = \frac{I_t}{\sum_{t=1}^{n} CM_t} \tag{5}$$

4 Case study

This chapter presents the specific policy that served as a case study and assesses the sustainable development impacts of this policy. Section 4.1 introduces GHG emissions trends in Mexico and an overview of the main climate change acts being implemented in the country as the context of the case study. Section 4.2 describes the specific policy to be assessed. Section 4.3 discusses the impact categories identified as well as specific impacts selected for the assessment. Section 4.4 presents the data used for the baseline and policy scenarios of the first climate action assessed within the case study, in addition to the qualitative and quantitative assessment results from this action as well as the sensitivity analyses. Section 4.5 presents the same information as the previous section focused on the second climate action of the case study. Last, Section 4.6 presents a summary and comparison of the results.

4.1 GHG emission trends in Mexico and climate policies

Mexico is the second largest country in Latin America with an area covering 1,972,550 km^2 (INEGI, N.D.a). Between 1990 and 2015, annual GHG emissions in the country grew 53% (INECC, 2017). These increased emissions were majorly affected by the production and use of energy, constituting two-thirds of the national total emissions (Veysey *et al.*, 2016). Figure 7 illustrates the latter in terms of million tonnes of CO_2 equivalent (CO_2 eq). The rise of emissions caused by the production and use of energy is mainly attributed to the country's demographic and economic trends as well as to its energy sources (Alemán-Nava *et al.*, 2014; Veysey *et al.*, 2016).

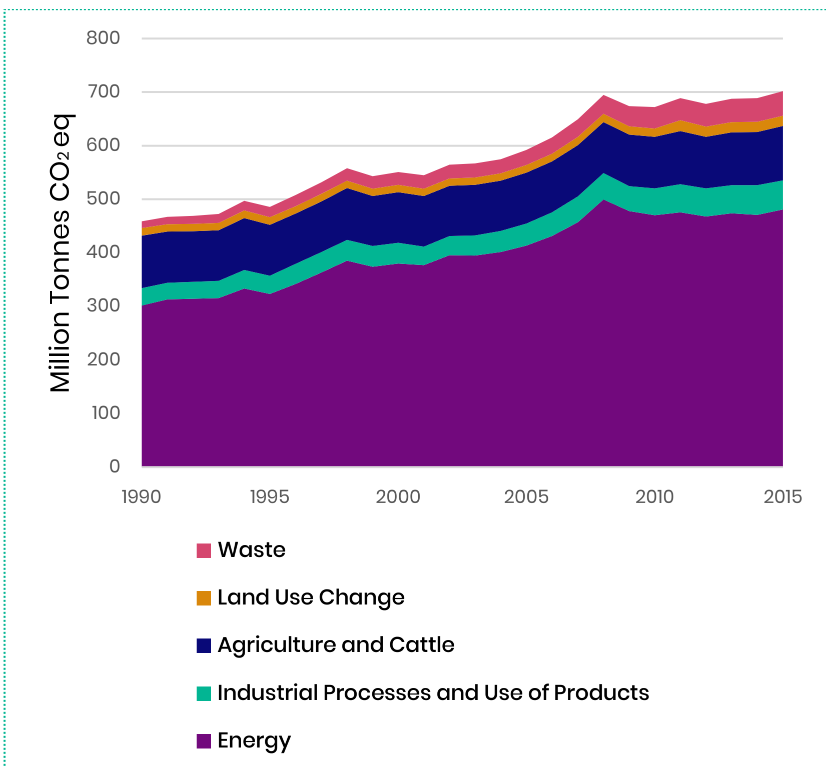

Figure 7 Mexican GHG emissions by source of emission (INECC, 2017).

Between 1990 and 2015, Mexico's population grew 47%, to 119,938,473 (INEGI, N.D.b.). This expansion of both population and economic activity has increased the demand for energy in a country where around 80% of its energy sources are fossil fuel-based and whose economy is based on the production of them (SIE, 2018).

Recognising the upward trends of GHG emissions, especially in the energy sector as well as seeking to promote a low-carbon future, the Mexican government has set ambitious targets in terms of GHG emissions and adoption of cleaner energy sources. Such targets include a 35% share of renewable energy sources in the national electricity grid by 2024, with an increase of 40% and 50% in 2035 and 2050, respectively, as well as a 22% unconditional reduction in national GHG and Short-Lived Climate Pollutants emissions by 2030, increasing to 50% in 2050 (SEMARNAT, 2015; CICC, 2013).

Mexico's goals follow 'a deep mitigation action required in climate stabilization scenarios and are among the most aggressive in the world, both for developed and developing regions' (Veysey *et al.*, 2016, p. 590). In order to achieve them, the country has enacted a range of climate and energy policies which are illustrated in Figure 8. Figure 8 also includes several other acts that contribute to Mexico's climate policy such as the Use of Renewable Energies and Funding for the Energy Transition Act (*Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética*) (DOF 28/11/2008, 2008), the General Act for Sustainable Forest Development (*Ley General de Desarrollo Forestal Sustentable*) (DOF 25/02/2003, 2003) as well as the 2013 Energy Reform and its Energy Transition Act *(Ley de Transición Energética)* (DOF 20/12/2013, 2013; Veysey *et al.*, 2016; Elizondo *et al.*, 2017).

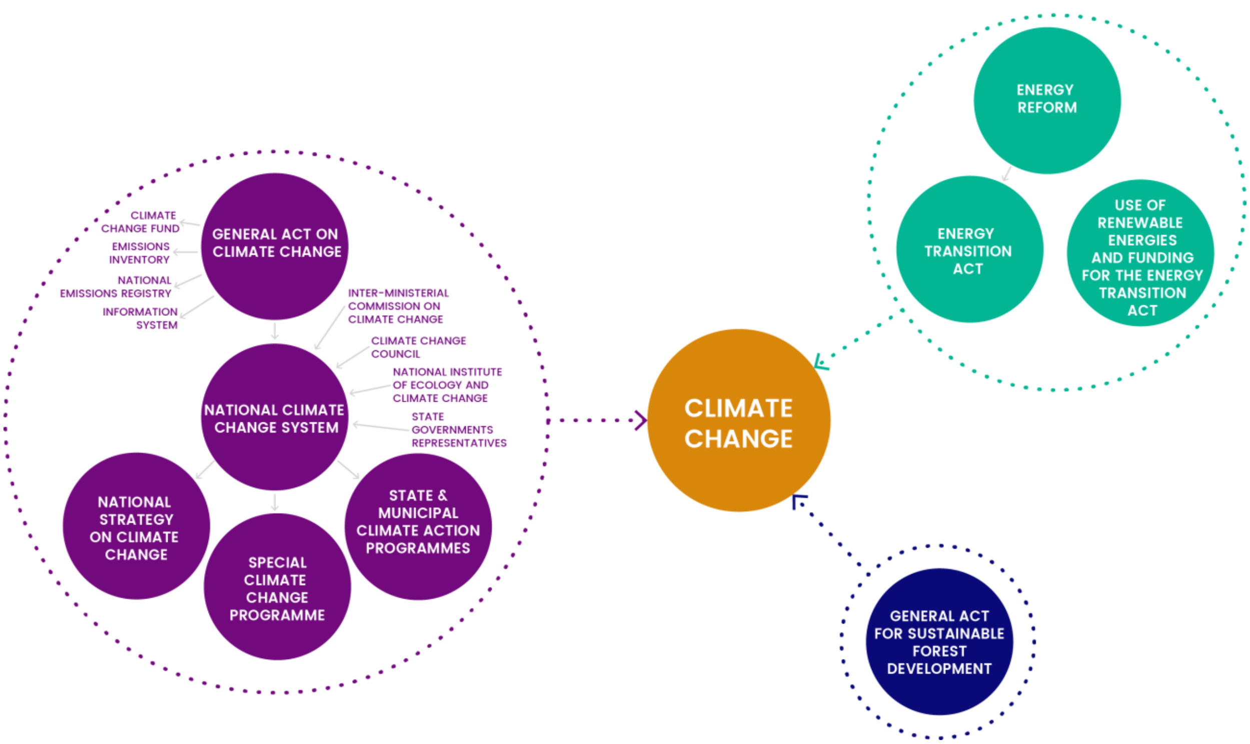

Figure 8 Mexican Climate Policy Ecosystem (DOF 25/02/2003, 2003; DOF 28/11/2008, 2008; DOF 06/06/2012, 2012; DOF 20/12/2013, 2013; Veysey et al., 2016; Elizondo et al., 2017).

The General Act on Climate Change (*Ley General de Cambio Climático*) (DOF 06/06/2012, 2012) was adopted in June 2012. It was created to regulate, promote, and establish the institutional and programmatic mechanisms for climate change adaptation and mitigation policies (Vesey et al., 2016). Within these mechanisms, the act mandates the creation of strategies and plans to achieve ambitious plans in terms of climate change (Elizondo *et al.*, 2017). At the centre of this act is the National Climate Change System, an institutional framework which is able to coordinate, develop, and implement climate policy via the following three main instruments: (i) National Strategy on Climate Change; (ii) Special Climate Change Programme; and (iii) State and Municipal Climate Action Programmes.

4.2 Jalisco's Carbon Management Plan

As a part of the State and Municipal Climate Action Programmes as well as the local Development Plan 2013-2030 for the State of Jalisco, the government of the aforementioned state, the fourth most populated in Mexico with 7,844,830 inhabitants (INEGI, N.D.c), introduced in 2015 its Carbon Management Plan. This plan was developed by the Ministry of Environment and Territorial Development (SEMADET) in cooperation with Carbon Trust Mexico and contains 96 actions on different scales whose main objective is to reduce by 2018, 40% of Jalisco's government-generated carbon emissions. In order to achieve that goal, four main action areas were identified: (i) energy efficiency in public buildings; (ii) use of renewable sources for energy; (iii) fuel change of the governmental vehicle fleet; and (iv) civil servants behavioural change towards energy usage (Mexico. Gobierno del Estado de Jalisco, 2015).

The total emissions generated in 2013 by the State of Jalisco were used as a baseline value, amounting to 123,681 tCO_2. Of these emissions, 52% were generated in public buildings including, schools, offices, cultural centres, and water pumping systems. The remaining 48% originated from the fuel type used to power the vehicle fleet owned by the government. From the 52% of emissions generated in public buildings, offices generated approximately 20% of these emissions, with 13,472 tCO_2 and an expenditure of 304,672,664 Mexican Pesos ($MX) (Ibid.).

4.2.1 Energy efficiency and renewable energy projects in public offices

Given the considerable role of public offices in the total emissions, 70 of the 96 projects included in the Carbon Management Plan were focused on energy retrofits in these offices. These 70 projects were planned to be implemented (or have been implemented) in 13 public buildings. The first retrofitted building, in April 2014, was the Sub-Administration of the Ministry of Planning, Administration, and Finance (*Secretaría de Planeación, Administración y Finanzas*) (SEPAF in Spanish). Two of the actions included in this retrofit were the installation of PV panels and the change of fluorescent lamps (FLs) to Light Emitting Diode (LED) lamps in the entire building.

These two main actions are the subjects of this thesis. The selection of these actions was based on their representativeness, since they were considered "average" retrofits common to most of the buildings intervened. Based on key recommendations from the ICAT SD Guidance, Table 8 presents basic information about the climate actions to be assessed.

Table 8 Policy or action basic information.

CRITERIA	DESCRIPTION
TITLE OF THE POLICY OR ACTION	Public Buildings Energy Efficiency Project – Pilot Test
TYPE OF POLICY OR ACTION	+ Voluntary agreement or action + Implementation of new technologies, processes or practices
STATUS OF THE POLICY OR ACTION	Implemented
DATE OF IMPLEMENTATION	April 2014
IMPLEMENTING ENTITY OR ENTITIES	Implementing entity - Ministry of Environment and Territorial Development (SEMADET) Public financing – Ministry of Planning, Administration, and Finance (SEPAF)
LEVEL OF THE POLICY OR ACTION	Sub-national level
GEOGRAPHIC COVERAGE	State of Jalisco (City of Guadalajara)
SECTORS TARGETED	Primary sectors: Government sector Sub-sectors: Energy sector (electricity generation)
DESCRIPTION OF SPECIFIC INTERVENTIONS	Selected retrofits in the SEPAF building: + Installation of 100 panels of 100Wp in the rooftop of the building + Replacement of 373 fluorescent lamp (FL) luminaires for Light Emitting Diode (LED) luminaires
TYPE OF ASSESSMENT (TEMPORAL CHARACTERISTICS)	Ex-post and ex-ante (April 2014 – December 2043)[3] – starting in the implementation date and finishing in the year the month the latest data is available.
OTHER RELATED POLICIES OR ACTIONS	+ The Carbon Management Plan from the State of Jalisco contains 94 more actions from the government sector in order to reduce CO_2 emissions by 40% (2013 baseline). + Specifically, in the SEPAF building, a climate change awareness-raising campaign was initiated in parallel to the retrofits.

4.3 Impact categories and specific impacts

The previous section introduced the climate actions to be assessed in this thesis belonging to the Carbon Management Plan of the State of Jalisco. This section presents the identification of impacts. The first sub-section reviews previous assessments relevant to the case study in order to analyse the impacts identified in each analysis. Both the second and third sub-section follow the ICAT SD Guidance for impact categories identification and for specific impact identification, respectively.

[3] Action 1 is assessed from April 2014 to December 2043. Action 2 is assessed from April 2014 to December 2031.

4.3.1 Review of sustainable development assessments relevant to the case study

The government of Jalisco, through its Ministry of Environment and Territorial Development (SEMADET), evaluated the cost-effectiveness of the actions by calculating the GHG emissions expected to be reduced, the cost of the interventions, and the expected savings. In other words, the analysis of this GHG emissions reduction policy remained in the climate change arena, by only analysing a limited range of environmental and economic factors.

As expressed by Harry and Morad (2013) as well as Morecraft and Cowan (2010), climate change issues and solutions require a deeper analysis of social, economic and environmental factors. Looking at climate policies from the bigger lens of sustainable development helps policymakers, decision-makers, and society at large to better understand the implications of an intervention. Furthermore, not doing so could compromise wider societal and environmental goals.

Due to the lack of sustainable development assessments of these specific climate actions, identified impacts from different assessments relevant to the case study were compared. Reports of the four sustainable development tools introduced in Chapter 2 were analysed. From these reports, only two studies were found relevant to this case study, namely, the Tunisian Building NAMA following the GHG Protocol and Action Standard, and the “Cuidemos México” project that used both the GHG Protocol and Action Standard and the CDM SD Tool. Therefore, the author performed a wider search of scientific literature focused on sustainable development assessments. Four main topics were selected, each of them widening in scope after the other, since no comprehensive sustainable development assessment was found for the narrower topics. The topics include (i) retrofits in public buildings; (ii) PV Panels; (iii) luminaires; and (iv) Mexican energy scenarios.

Five out of seven assessments that included the three dimensions of sustainable development followed a life cycle thinking approach. From those five, three used the Life Cycle Sustainability Assessment (LCSA) framework to determine the sustainability impacts. Whilst LCA was the most common method used to analyse environmental impacts, economic impacts were mostly calculated using Life Cycle Costing (LCC). Social impacts varied depending on the authors’ selection of groups benefited or affected by the policies or actions. On the one hand, assessments including the “Cuidemos México” project as well as the energy and water retrofits in Australian public buildings analysed the social impacts through the lens of the final users. On the other hand, studies utilising the Social Life Cycle Assessment (S-LCA) method mostly focused on groups of people involved in early stages of the life cycle, namely, the manufacturing stage. The findings of the impact analysis are summarised in Table 9.

Table 9 Comparison of sustainable development assessments relevant to the case study.

Topic	Framework/Guidance Used	Social Impacts	Environmental Impacts	Economic Impacts	Author(s)
Tunisian Building NAMA	GHG Protocol		X		N/A
"Cuidemos Mexico" - Distribution of 30 million compact fluorescent lamps (CFLs) to Mexican households	CDM / GHG Protocol	X	X	X	N/A
Retrofits in European Public Buildings	None, but a series of environmental and economic indices based on the Environmental Product Declaration (EPD) format were used.		X		(Ardente *et al.*, 2011)
Retrofits in European Buildings	None, the author used Life Cycle Assessment (LCA) to calculate the environmental impacts.		X		(García-Pérez, Sierra-Pérez and Boschmonart-Rives, 2017)
Energy and Water Retrofits in Australian Public Buildings	The study is not an assessment but looks into links between retrofits and potential impacts.	X ($[4])	X ($)	X	(Bertone *et al.*, 2016)
Solar Panels	Life Cycle Sustainability Assessment (LCSA): + Environmental LCA + Social LCA (S-LCA) + Life Cycle Costs (LCC)	X	X	X	(Traverso *et al.*, 2012)
Solar Panels	Authors look for gaps in LCA especially those related to health and safety	X	X	X	(Bakhiyi, Labrèche and Zayed, 2014)
Solar Panels	Life Cycle Sustainability Assessment (LCSA): + Environmental LCA + Social LCA (S-LCA) + Life Cycle Costs (LCC)	X	X	X	(Gundes, 2016)
Solar Panels	Framework created by authors based on a life cycle perspective	X	X	X	(Li, Roskilly and Wang, 2017)

[4] The authors present options of giving a monetary value to non-economic variables.

Luminaires	Life Cycle Assessment (LCA)		X		(Navigant Consulting Europe, 2009)
Fluorescent Lamps	Life Cycle Assessment (LCA)		X		(Tähkämö *et al.*, 2014)
Mexican Energy Scenarios for 2050	Life Cycle Sustainability Assessment (LCSA): + Environmental LCA + Social LCA (S-LCA) + Life Cycle Costs (LCC)	X	X	X	(Santoyo-Castelazo and Azapagic, 2014)

4.3.2 Impact categories identification

Based on the review of existing assessments presented in the previous sub-section as well as an analysis based on a non-exhaustive but comprehensive list of impact categories from the ICAT SD Guidance, Table 10 presents the preliminary impact categories selected for the case study. As can be observed in Table 10, the first column contains the three dimensions of sustainable development (environmental, social, and economic). These dimensions are divided into groups of impact categories, such as air, water, labour conditions, and socio-economic impacts. Furthermore, these groups of impact categories are divided into individual impact categories (e.g. the group of impact category "air" is comprised by impact categories such as GHG emissions, air quality, and ozone formation). It is at this level that the identification of potential impacts based on literature review and existing reports is performed. Each of the remaining columns represents a specific stage from a life cycle perspective (e.g. manufacturing, use, and disposal). Moreover, the last column is labeled non-life cycle in order to include identified impacts that do not belong to any specific life cycle phase or are a result of the selected policy as a whole.

Table 10 Impact categories applicable to the "Public Buildings Energy Efficiency" case study. Adapted from (Bakhiyi, Labrèche and Zayed, 2014; Dubey, Jadhav and Zakirova, 2013; Santoyo-Castelazo and Azapagic, 2014; Li, Roskilly and Wang, 2017; Traverso et al., 2012).

DIMENSION	GROUPS OF IMPACT CATEGORIES	IMPACT CATEGORIES	RAW MATERIAL EXTRACTION	MANUFACTURING	ASSEMBLY	INSTALLATION	USE	DEINSTALLATION	WASTE PROCESSING	DISPOSAL	TRANSPORT	NON-LIFE CYCLE
ENVIRONMENTAL	AIR	GHG EMISSIONS	X	X	X	X	X	–	X	X	X	–
		OZONE DEPLETION	X	X	X	X	X	–	X	X	X	–
		AIR QUALITY	X	X	X	X	X	–	X	X	X	–
		OZONE FORMATION	X	X	X	X	X	–	X	X	X	–
		TOXIC CHEMICALS RELEASED TO AIR	X	X	X	X	X	–	X	X	X	–
	WATER	FRESHWATER CONSUMPTION	X	X	X	X	X	–	X	X	X	–
		WATER QUALITY	X	X	X	X	X	–	X	X	X	–
		BIODIVERSITY OF WATER ECOSYSTEMS	X	X	X	X	X	–	X	X	X	–
		TOXIC CHEMICALS RELEASED TO WATER	X	X	X	X	X	–	X	X	X	–
	LAND	LAND USE	X	X	X	X	X	–	X	–	–	–
		SOIL QUALITY	X	X	X	X	X	–	X	X	X	–
		BIODIVERSITY OF TERRESTRIAL ECOSYSTEMS	X	X	X	X	X	–	X	X	X	–
	RESOURCES	MINERAL RESOURCES DEPLETION	X	X	X	X	X	–	X	X	X	–
		FOSSIL RESOURCES DEPLETION	X	X	X	X	X	–	X	X	X	–
	ENERGY	RENEWABLE ENERGY GENERATION	–	–	–	–	X	X	–	–	–	X
		RENEWABLE ENERGY SHARE	–	–	–	–	X	–	–	–	–	X
	WASTE	WASTE GENERATION AND DISPOSAL	X	X	–	–	–	–	X	X	X	–

Table 10 (continued)

DIMENSION	GROUPS OF IMPACT CATEGORIES	IMPACT CATEGORIES	RAW MATERIAL EXTRACTION	MANUFACTURING	ASSEMBLY	INSTALLATION	USE	DEINSTALLATION	WASTE PROCESSING	DISPOSAL	TRANSPORT	NON-LIFE CYCLE
SOCIAL	LABOUR CONDITIONS	HEALTH AND SAFETY OCCUPATIONAL RISKS	X	X	X	X	X	X	X	X	X	
		WAGES	X	X	X	X	X	X	X	X	X	–
		WORKING HOURS	X	X	X	X	X	X	X	X	X	–
		DISCRIMINATION	X	X	X	X	X	X	X	X	X	–
		FORCED LABOUR	X	X	X	X	X	X	X	X	X	–
		CHILD LABOUR	X	X	X	X	X	X	X	X	X	–
	CAPACITY, SKILLS, AND KNOWLEDGE DEVELOPMENT	TRAINING	–	X	X	X	–	X	X	–	–	–
		CLIMATE CHANGE AWARENESS	–	–	–	–	–	–	–	–	–	X
	IMAGE & PERCEPTION	PUBLIC IMAGE	–	–	–	–	–	–	–	–	–	X
	ENERGY	LOCAL R&D	–	–	–	–	–	–	–	–	–	X
		PUBLIC ACCEPTANCE OF RENEWABLES	–	–	–	–	X	–	–	–	–	X
ECONOMIC	SOCIO-ECONOMIC	JOBS	X	X	X	X	X	X	X	X	–	–
		INCOME GENERATION	X	X	X	X	X	X	X	X	–	–
		LOCAL ECONOMY	–	X	X	X	X	–	–	–	–	–
	COSTS AND COST SAVINGS	LIFE CYCLE COSTS	–	–	–	X	X	X	X	X	–	–
		POLICY IMPLEMENTATION COSTS	–	–	–	–	–	–	–	–	–	X
		POLICY COST-EFFECTIVENESS	–	–	–	–	–	–	–	–	–	X
		COST SAVINGS	–	–	–	–	–	–	–	–	–	X
		PAYBACK PERIOD	–	–	–	–	–	–	–	–	–	X
	ENERGY MARKET	ENERGY INDEPENDENCE	–	–	–	–	–	–	–	–	–	X
		ENERGY DIVERSIFICATION	–	–	–	–	–	–	–	–	–	X
	OTHER INVESTMENTS	SUPPORTING INFRASTRUCTURE	–	–	–	–	–	–	–	–	–	X
		REBOUND EFFECTS	–	–	–	–	–	–	–	–	–	X

These preliminary impact categories were reviewed by the author in addition to four different types of stakeholders: two civil servants working at SEMADET, a representative of Carbon Trust Mexico, a civil servant from SEPAF, and the PV panels supplier. In order to perform this review, semi-structured interviews were conducted, following key recommendations of the ICAT SD Guidance and the ICAT Stakeholder Participation Guidance. An analysis of other stakeholders, found in Appendix 2, was also performed with the intention of including their opinions in the review, but no interviews with these stakeholders were possible. The review with the contacted stakeholders included analysing the significance and relevance of each impact category, whilst ensuring the comprehensiveness of the list. Tables 11 to 13 show the selected impacts resulting from the analysis previously described. It should be noted that several environmental impact categories marked in Table 11 (*) were not considered relevant by stakeholders, thus, were not considered in the specific impacts identification. However, these impacts are generally analysed in LCAs, therefore, they were calculated in the model. Nevertheless, only the impacts with significant results were presented in the qualitative assessment.

Table 11 Selection of environmental impact categories based on their relevance, significance, and comprehensiveness.

DIMENSION	IMPACT CATEGORIES	RELEVANCE	SIGNIFICANCE	SOURCE
ENVIRONMENTAL	GHG EMISSIONS	X	X	"Tunisian Building NAMA", (Bakhiyi, Labrèche and Zayed, 2014), (Chen, Zhang and Kim, 2017), (García-Pérez, Sierra-Pérez and Boschmonart-Rives, 2017), (Gundes, 2016), (Navigant Consulting Europe, 2009), (Tähkämö *et al.*, 2013), (Tähkämö *et al.*, 2014), (Traverso *et al.*, 2012), Stakeholders
	OZONE DEPLETION*	-	X	(Bakhiyi, Labrèche and Zayed, 2014), (García-Pérez, Sierra-Pérez and Boschmonart-Rives, 2017), (Gundes, 2016), (Navigant Consulting Europe, 2009), (Tähkämö *et al.*, 2013), (Tähkämö *et al.*, 2014), (Traverso *et al.*, 2012), Stakeholders
	AIR QUALITY	X	X	Ibid.
	OZONE FORMATION*	-	X	Ibid.
	TOXIC CHEMICALS RELEASED TO AIR	X	X	Ibid.
	FRESHWATER CONSUMPTION	X	X	Ibid.
	WATER QUALITY*	-	X	Ibid.
	BIODIVERSITY OF WATER ECOSYSTEMS*	-	X	Ibid.

Table 11 (continued)

DIMENSION	IMPACT CATEGORIES	RELEVANCE	SIGNIFICANCE	SOURCE
ENVIRONMENTAL	TOXIC CHEMICALS RELEASED TO WATER	X	X	Ibid.
	LAND USE	X	X	Ibid.
	SOIL QUALITY*	-	X	Ibid.
	BIODIVERSITY OF TERRESTRIAL ECOSYSTEMS*	-	X	Ibid.
	MINERAL RESOURCES DEPLETION	X	X	Ibid.
	FOSSIL RESOURCES DEPLETION	X	X	Ibid.
	RENEWABLE ENERGY GENERATION	X	X	Stakeholders
	RENEWABLE ENERGY SHARE	X	X	Stakeholders
	WASTE GENERATION AND DISPOSAL	X	X	Stakeholders

Table 12 Selection of social impact categories based on their relevance, significance, and comprehensiveness.

DIMENSION	IMPACT CATEGORIES	RELEVANCE	SIGNIFICANCE	SOURCE
SOCIAL	HEALTH AND SAFETY OCCUPATIONAL RISKS	X	X	(Bakhiyi, Labrèche and Zayed, 2014), (Gundes, 2016), (SHDB, N.D.), (Traverso *et al.*, 2012), Stakeholders
	WAGES	-	X	(Gundes, 2016), (SHDB, N.D.), (Traverso *et al.*, 2012), Stakeholders
	WORKING HOURS	-	X	Ibid.
	DISCRIMINATION	-	X	Ibid.
	FORCED LABOUR	-	X	Ibid.
	CHILD LABOUR	-	X	Ibid.
	TRAINING	X	X	“Cuidemos México” project, Stakeholders
	CLIMATE CHANGE AWARENESS	X	X	“Cuidemos México” project, (Dubey *et al.*, 2014), Stakeholders
	PUBLIC IMAGE	-	-	Stakeholders
	LOCAL R&D	X	X	(Bakhiyi, Labrèche and Zayed, 2014), Stakeholders
	PUBLIC ACCEPTANCE OF RENEWABLES	X	X	Stakeholders

Table 13 Selection of economic impact categories based on their relevance, significance, and comprehensiveness.

DIMENSION	IMPACT CATEGORIES	RELEVANCE	SIGNIFICANCE	SOURCE
ECONOMIC	JOBS	X	X	(Bakhiyi, Labrèche and Zayed, 2014), (Dubey *et al.*, 2014)
	INCOME GENERATION	-	X	Stakeholders
	LOCAL ECONOMY	X	X	"Cuidemos México" project, Stakeholders
	LIFE CYCLE COSTS	-	X	(Li, Roskilly and Wang, 2017), (Santoyo-Castelazo and Azapagic, 2014), (Traverso *et al.*, 2012)
	POLICY IMPLEMENTATION COSTS	-	X	Ibid.
	POLICY COST-EFFECTIVENESS	X	X	Ibid.
	COST SAVINGS	X	X	Ibid.
	PAYBACK PERIOD	X	X	Ibid.
	ENERGY INDEPENDENCE	-	-	Stakeholders
	ENERGY DIVERSIFICATION	-	X	(Dubey *et al.*, 2014), Stakeholders
	SUPPORTING INFRASTRUCTURE	-	X	Stakeholders
	REBOUND EFFECTS	X	X	"Cuidemos México" project, Stakeholders

4.3.3 Specific impacts identification

Following the selection of impact categories, an analysis of specific impacts was performed using causal chain diagrams. These diagrams were used to identify the sustainable development impacts caused by the selected climate actions through a series of logically and sequentially interlinked stages (intermediate impacts) (ICAT, 2017). Figures 9 to 11 describe the specific impacts for the environmental, social, and economic dimensions, respectively.

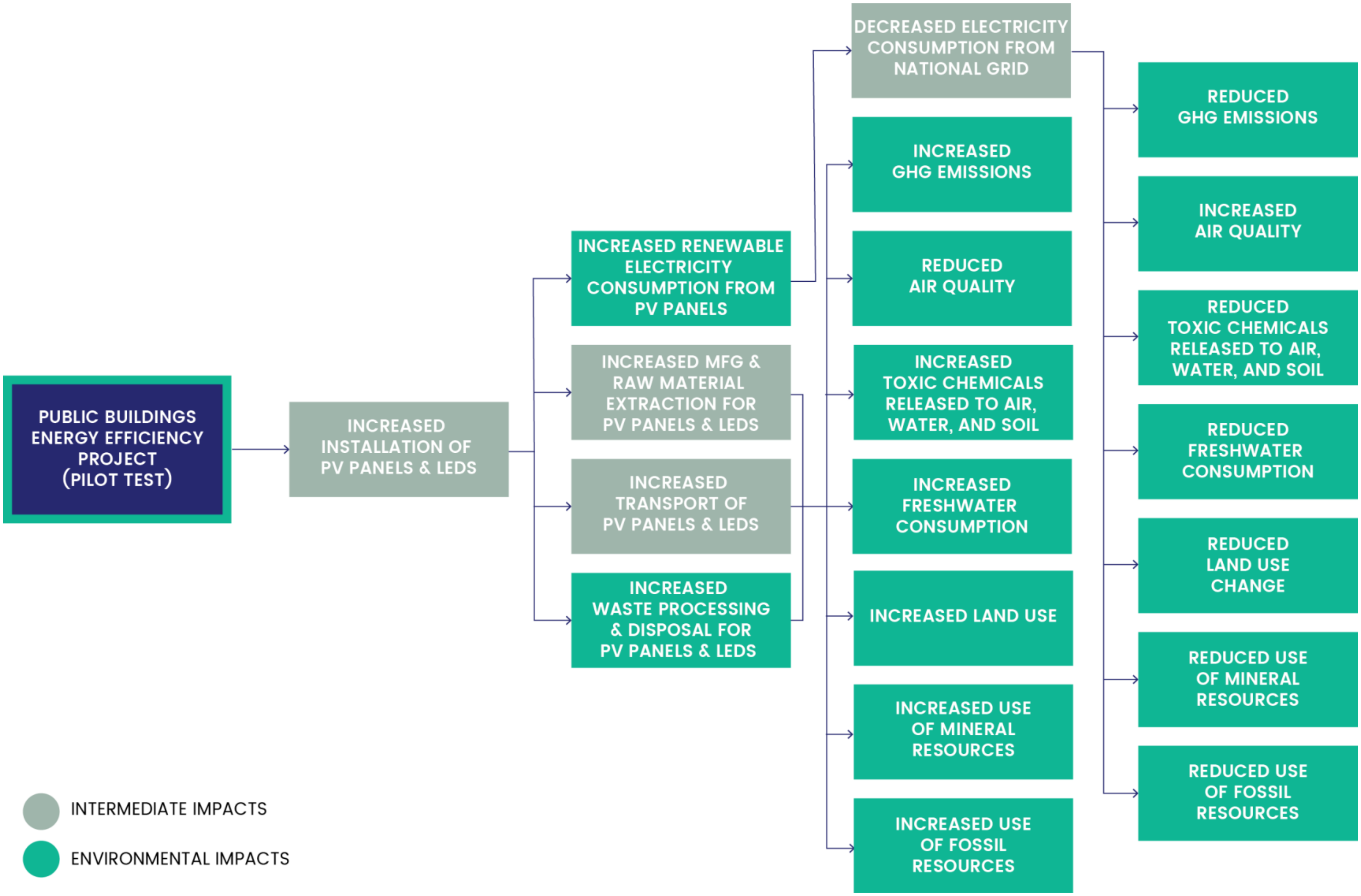

Figure 9 Environmental scientific impacts.

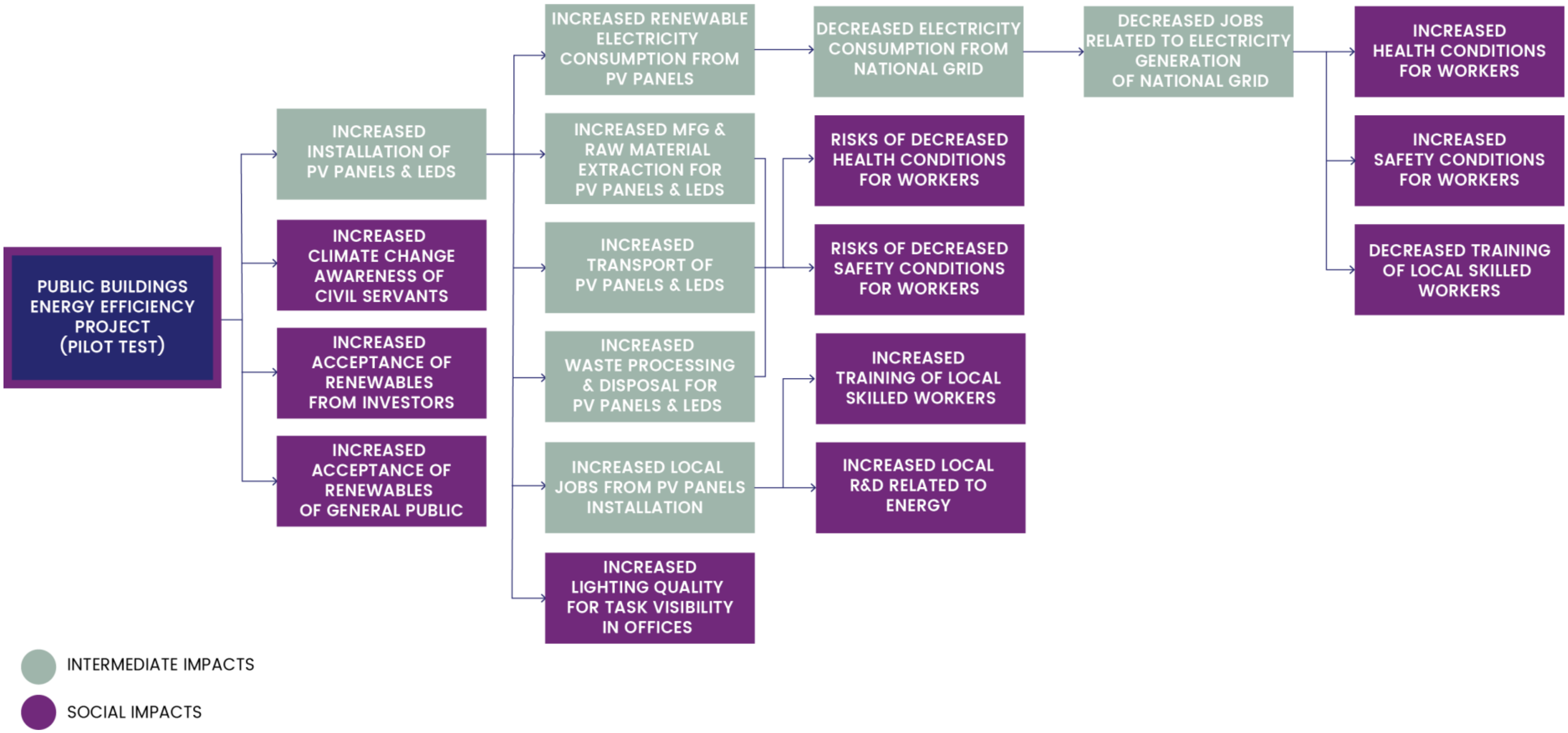

Figure 10 Social specific impacts.

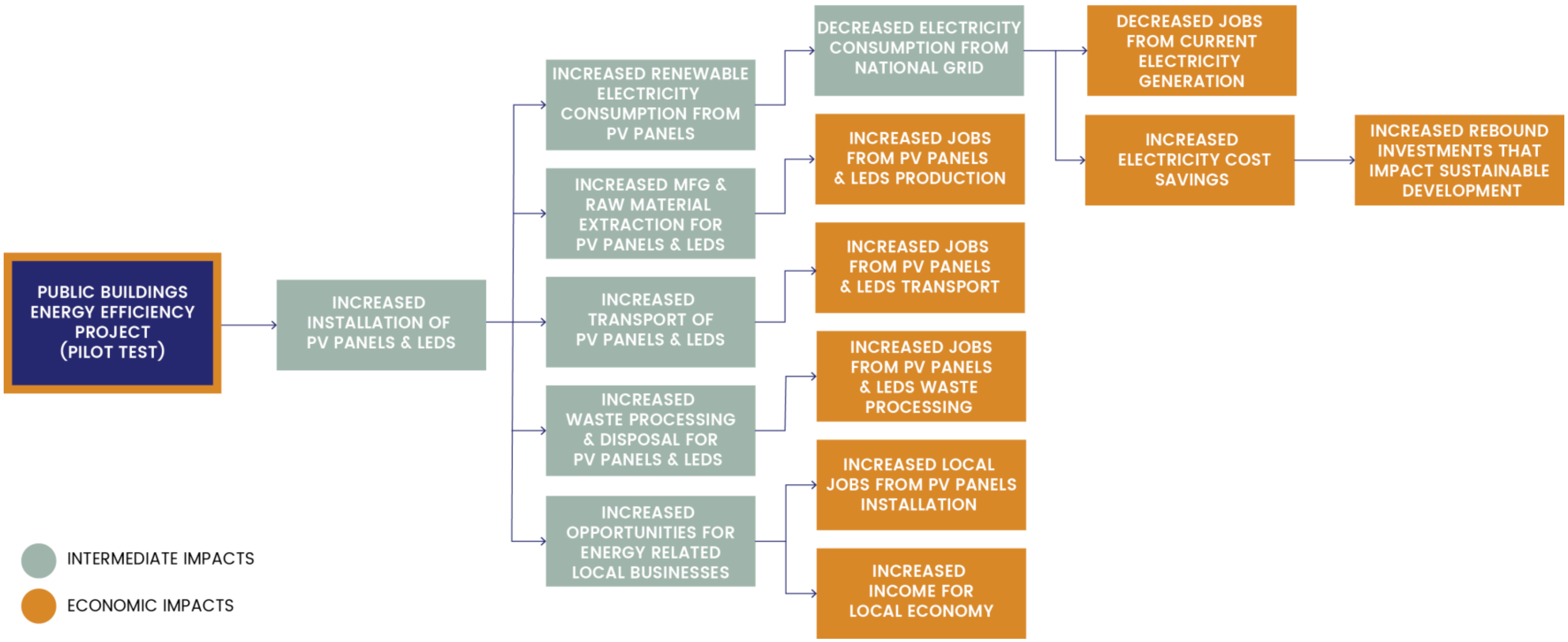

Figure 11 Economic specific impacts.

4.4 Climate action 1 – PV panels

This section presents the first climate action of the case study where 100 PV panels of 100Wp were installed in the SEPAF building in 2014.

4.4.1 Baseline scenario

In the baseline scenario it was assumed that during the assessed period, from April 2014 to December 2043, the electricity consumed in the SEPAF building derived 100% from the national grid. The functional unit for this first climate action is the consumption of electricity (kWh) in the SEPAF building for 30 years (April 2014 – December 2043). Table 14 shows the total consumption per year from 2014 to 2018 (kWh), the actual domestic electricity prices (MX$/kWh), and the total operating costs for electricity (MX$) incurred by the Ministry of Planning, Administration, and Finance (SEPAF). The information was provided by the SEMADET, based on internal ministerial accounting records. In order to assess the future impacts from 2019 to 2043, it was assumed that the consumption will equal 260,000 kWh annually and the electricity price will increase 3% each year (SENER, 2017). Furthermore, a tariff-3- based domestic electricity price of 2.54 (MX$/kWh) is assumed for this period of years based on historic prices (SIE, 2017) as well as a real social discount rate for the project of 3.3% (Lopez, 2008).

Table 14 Annual electricity consumption and electricity in the SEPAF building. Source – BASED ON RECORDS (SEMADET).

	2014 (Apr to Dec)	**2015**	**2016**	**2017**	**2018**
TOTAL CONSUMPTION (kWh)	246,782	263,789	256,939	263,708	263,708[5]
DOMESTIC ELECTRICITY PRICE (MX$/kWh)	1.9789	1.5954	1.6113	2.3176	2.3176[5]
TOTAL OPERATING COSTS FOR ELECTRICITY (MX$)	488,350	420,855	414,009	611,168	611,168[5]

Although the electricity mix varies across Mexican federal entities (Navarro-Pineda, Handler and Sacramento-Rivero, 2017), it was assumed that the electricity mix used in the assessed building had the same composition as the national average. Table 15 presents this mix, categorised by primary energy, for every assessed year based on records of the Mexican Energy Information System (SIE), which is maintained by the Ministry of Energy (SENER). The electricity mix for the year 2018 was assumed to be the same as the mix for 2017 since no updated records were found. Table 13 also contains the electricity mix forecasted for the years 2019 to 2031 based on data by the Ministry of Energy. Furthermore, the electricity mix from 2032 until 2043 was assumed to remain the same as the 2031 values. Data in Table 15 was used to update the existing processes modelled to assess the Mexican electricity mix in the Ecoinvent v3.4 database through the SimaPro software.

[5] Values estimated based on the previous year consumption.

Table 15 Mexico's electricity mix categorised by primary energy used in the assessment. Adapted from (SIE, 2018; SENER, 2017).

	2014	2015	2016	2017	2018[6]	2019	2020	2021	2022	2023
NATURAL GAS	52.36%	54.18%	54.67%	52.92%	52.92%	52%	55%	54%	53%	53%
HYDROPOWER	14.77%	11.51%	11.07%	11.68%	11.68%	10%	10%	9%	9%	9%
THERMOELECTRIC (HEAVY FUEL OIL)	12.96%	13.66%	13.99%	16.14%	16.14%	9%	5%	4%	4%	3%
COAL (HARD COAL & LIGNITE)	13.01%	12.86%	12.99%	11.94%	11.94%	11%	11%	10%	10%	10%
NUCLEAR	3.74%	4.43%	4.01%	4.22%	4.22%	3%	3%	3%	3%	3%
GEOTHERMAL	2.32%	2.40%	2.29%	2.30%	2.30%	1%	1%	1%	2%	2%
WIND	0.80%	0.91%	0.93%	0.76%	0.76%	7%	8%	10%	10%	11%
PHOTOVOLTAICS	0.005%	0.005%	0.005%	0.005%	0.005%	2.1%	2.6%	3.1%	3.1%	3%
BIOFUELS & COGENERATION	0%	0%	0%	0%	0%	3%	4%	4%	4%	4%

	2024	2025	2026	2027	2028	2029	2030	2031	2032-2043[7]
NATURAL GAS	52%	53%	53%	52%	52%	51%	50%	48%	48%
HYDROPOWER	9%	9%	9%	9%	9%	9%	9%	9%	9%
THERMOELECTRIC (HEAVY FUEL OIL)	1%	0%	0%	0%	0%	0%	0%	0%	0%
COAL (HARD COAL & LIGNITE)	9%	9%	9%	9%	8%	7%	6%	6%	6%
NUCLEAR	3%	3%	3%	3%	3%	5%	7%	8%	8%
GEOTHERMAL	2%	2%	2%	3%	3%	3%	3%	3%	3%
WIND	12%	12%	13%	13%	13%	14%	14%	15%	15%
PHOTOVOLTAICS	3%	3.2%	3.1%	3.1%	3%	3%	3%	2.6%	2.6%
BIOFUELS & COGENERATION	5%	5%	5%	5%	5%	5%	6%	5%	5%

[6] Values estimated based on the previous year electricity mix (2017).
[7] Values estimated based on the previous year electricity mix (2031).

In order to assess the sustainable development impacts of this first climate action, system boundaries were defined and are presented in Figure 12. These system boundaries include all the sources of electricity required to generate the aforementioned electricity mix, such as extraction, processing, refining or any other transformative procedure depending on the technology used, transport, transmission networks, power plants, and use stage (electricity consumption). The impacts of power plants, calculated in Ecoinvent v3.4 and based on standard lifetimes, were attributed to 1 year in order to be proportionate to the model. However, different boundaries were defined for the social and economic assessments which focused exclusively on local (in-jurisdiction) impacts from the use phase.

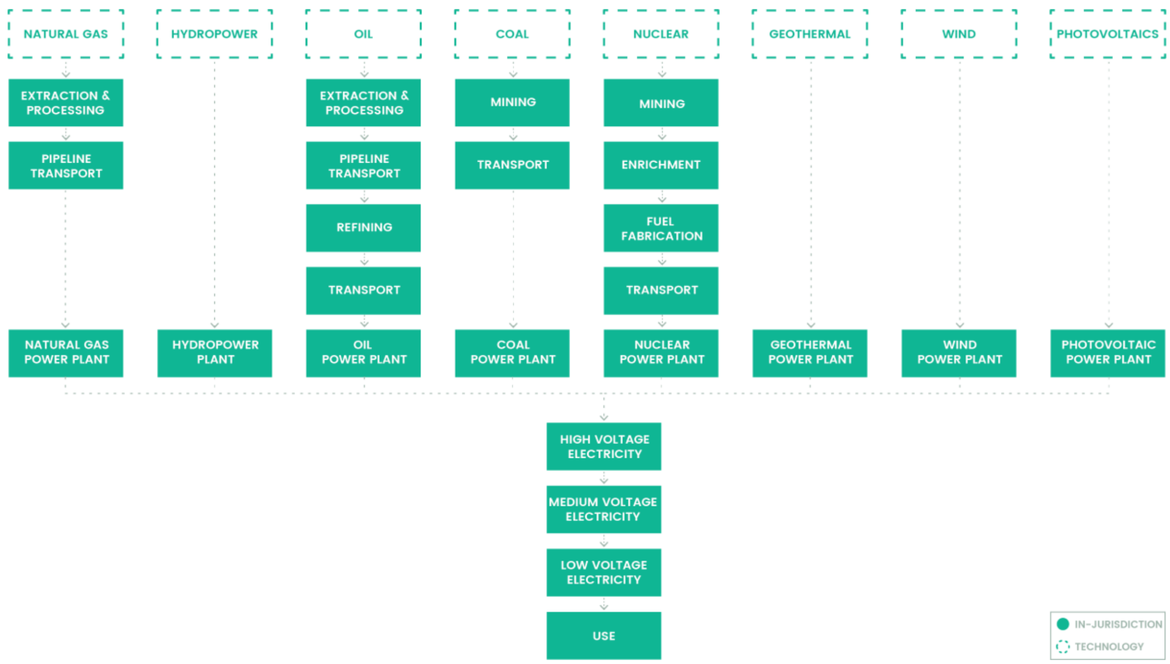

Figure 12 Simplified flowchart with system boundaries of the electricity generation in Mexico. Adapted from (Navarro-Pineda, Handler and Sacramento-Rivero, 2017).

4.4.2 Policy scenario

The policy scenario follows the retrofits performed to the SEPAF building based on the Carbon Management Plan. During the assessed period of this scenario, from April 2014 to December 2043, approximately 6% of the electricity consumed in the SEPAF building is assumed to be generated by solar panels installed on its rooftop. The remaining 94% of the electricity is assumed to be consumed from the national grid.

Table 16 shows the total consumption per year (kWh), the Mexican tariff-3-based domestic electricity prices (MX$/kWh), and the total operating costs for electricity (MX$) incurred by the Ministry of Planning, Administration, and Finance (SEPAF). The information was provided by SEMADET, based on internal ministerial accounting records. Similar to the baseline scenario, in order to assess the future impacts from 2019 to 2043, it was assumed that the consumption will equal 260,000 kWh annually, the electricity consumption of the PV panels will remain the same, and the electricity price will increase 3% each year (SENER, 2017). Furthermore, a tariff-3- based domestic electricity price of 2.54 (MX$/kWh) is assumed for this period of years based on historic prices (SIE, 2017) as well as a real social discount rate for the project of 3.3% (Lopez, 2008). In order to properly compare the baseline and policy scenario, the functional unit used to assess both scenarios is the consumption of electricity (kWh) in the SEPAF building for 30 years (April 2014 – December 2043).

Table 16 Annual electricity consumption and costs for electricity in the SEPAF building. Source – BASED ON RECORDS (SEMADET).

	2014 (Apr to Dec)	2015	2016	2017	2018
TOTAL CONSUMPTION (kWh)	246,782	263,789	256,939	263,708	263,708[8]
CONSUMPTION MEXICAN GRID (kWh)	235,719	249,038	242,188	248,957	248,957[8]
CONSUMPTION PV PANELS (kWh)	11,063	14,751	14,751	14,751	14,751
DOMESTIC ELECTRICITY PRICE (MX$/kWh)	1.9789	1.5954	1.6113	2.3176	1.7804[8]
TOTAL OPERATING COSTS FOR ELECTRICITY (MX$)	466,457	397,321	390,241	576,981	576,981[8]

Data concerning the entire life cycle of the PV panels was adapted from the existing process in the Ecoinvent database v.3.4, *Photovoltaic flat-roof installation, 3kWp multi-Si, on roof {MX}| photovoltaic flat-roof installation, 3kWp, multi-Si, on roof | APOS, U*, since it is originally set up for 210W panels. The adaptations made to the existing process were calculated based on 100 multi-Si solar panel of 0.99 x 1.65 [m], and a nominal power of 100W. With an observed annual average solar irradiation of 2034 kWh/m^2 per year, an observed performance ratio of 0.72 m^2/kWp, a panel efficiency of 13.2 and a lifetime of 30 years. These existing stages in the aforementioned database include data on waste processing and disposal, however, it is assumed that the manufacturer performs this operation, with the exception of aluminium recycling used in the mounting system which is done in Mexico. Furthermore, no reliable data was found to model these stages separately. Therefore, impacts from waste processing, other than aluminium recycling, are not disaggregated in the results.

Other key parameters used in the economic assessment, conducted from the perspective of the government of Jalisco, include the total investment costs of the PV panels and the real discount rate. The actual total investment costs were MX$622,821.00, which started at installation and do not include disposal costs; maintenance costs are also not included. The investment costs

[8] Values estimated based on the previous year consumption.

were found in internal ministerial records and progress reports provided by the SEMADET, thus, no uncertainty related to these values are assumed.

In order to assess the sustainable development impacts of this first climate action, Figure 13 presents a simplified flowchart with the system boundaries used to environmentally assess the PV panels installed in the SEPAF building. These panels were assumed to be shipped to Mexico from Canada, based on the brand installed. However, the material extraction and manufacturing of the panels is calculated given the global average followed by the database. Figure 13 also presents a separation of in-jurisdiction and out-of-jurisdiction stages from the entire life cycle of the PV panels. As mentioned in the baseline scenario, both the social and economic assessment only focus on specific stages from the system boundaries presented. These stages are the installation and use stage of the PV panel. Furthermore, cost savings impacts were analysed from the point of view of the government of Jalisco, as the owner of the building.

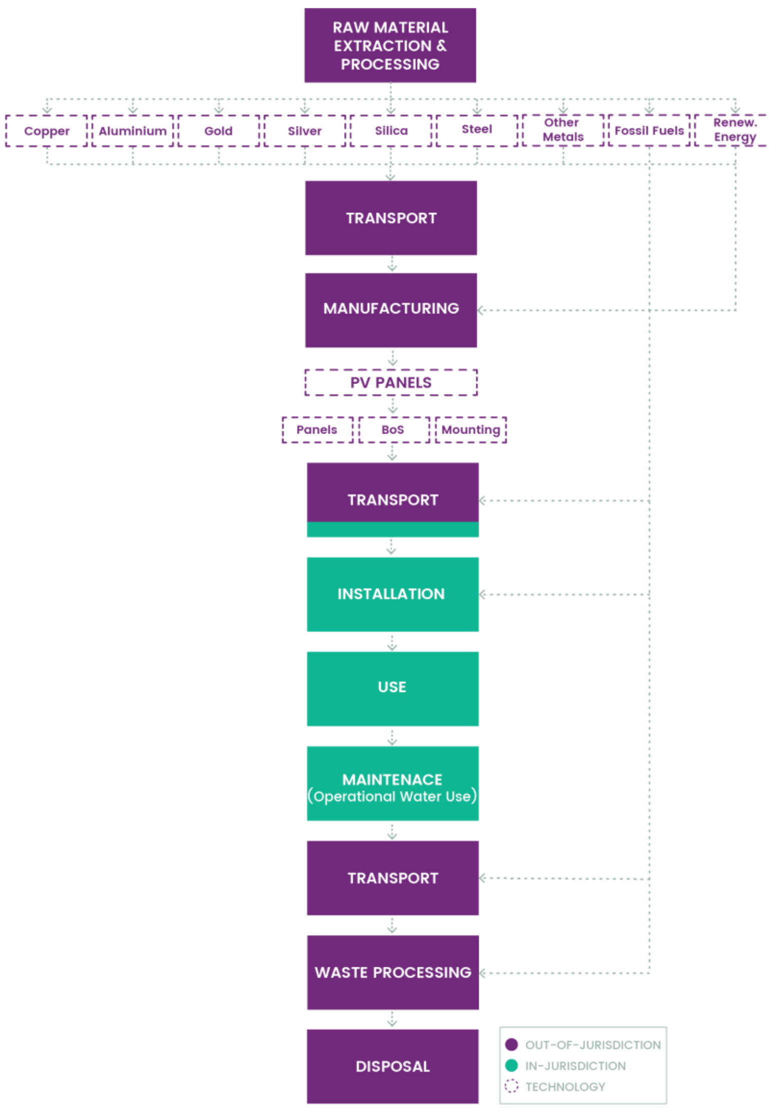

Figure 13 Simplified flowchart with system boundaries of PV panels installed in the SEPAF building.

4.4.3 Qualitative assessment

Based on the specific impacts identified in the case study, summarised in Figures 9 to 11, the qualitative assessment was performed by analysing each of the impacts based on their significance. As explained in Chapter 3, the significance of an impact is determined by its magnitude and likelihood. Furthermore, these two criteria were assessed based on literature review and supported by the opinion of stakeholders. Results of the environmental, social, and economic qualitative assessment are summarised in Table 17. Whilst Table 17 presents the entirety of specific impacts previously identified, this sub-section only discusses the specific impacts classified as significant that were not possible to quantify, thus, not included in the quantitative assessment. Since the totality of specific environmental impacts identified in the case study was included in the quantitative assessment boundary, these impacts are not discussed in the qualitative assessment.

As can be observed in Table 17, the first column contains the impact categories determined as relevant in earlier steps. These impact categories are divided into specific impacts, selected in Figures 9 to 11, and further analysed in order to determine their significance. The nature of the impacts (positive or negative) is also included in Table 17. It is worth noting that three specific impacts were considered as significant effects of the two climate actions together. However, since a disaggregation of results for each of the actions was not possible, the results are presented in this sub-section. These three specific impacts are: (i) climate change awareness of civil servants (social impact); (ii) increased acceptance of energy retrofit actions (social impact); and (iii) rebound effects (economic impact).

Table 17 Qualitative assessment summary of Climate Action 1 – PV Panels.

IMPACT CATEGORIES	SPECIFIC IMPACTS	IN- OR OUT-OF-JURISDICTION	LIKELIHOOD	MAGNITUDE	POSITIVE OR NEGATIVE IMPACT	SIGNIFICANCE	FEASIBILITY TO QUANTIFY	INCLUSION IN QUANTITATIVE ASSESSMENT BOUNDARY
GHG EMISSIONS	Reduced GHG emissions from decreased electricity consumption and generation of national grid	IN	VERY LIKELY	MAJOR	+	SIGNIFICANT	FEASIBLE	YES
	Increased GHG emissions from increased production, transport, waste processing, disposal of PV panels	IN/OUT	VERY LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
AIR QUALITY	Increased air quality from decreased electricity consumption and generation of national grid	IN	POSSIBLE	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Reduced air quality from increased production, transport, waste processing, disposal of PV panels	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
HUMAN TOXICITY	Reduced human toxicity from decreased electricity consumption and generation of national grid	IN	LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased human toxicity from increased production, transport, waste processing, disposal of PV panels	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
FRESHWATER CONSUMPTION	Reduced freshwater consumption from decreased electricity consumption and generation of national grid	IN	LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased freshwater consumption from increased production, transport, waste processing, disposal of PV panels	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
LAND USE	Reduced land use from decreased electricity consumption and generation of national grid	IN	LIKELY	MINOR	+	NOT SIGNIFICANT	N/A	YES
	Increased land use from increased production, transport, waste processing, disposal of PV panels	IN/OUT	LIKELY	MINOR	-	NOT SIGNIFICANT	N/A	NO
MINERAL RESOURCES DEPLETION	Reduced mineral resources depletion from decreased electricity consumption and generation of national grid	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased mineral resources depletion from increased production, transport, waste processing, disposal of PV panels	IN/OUT	VERY LIKELY	MAJOR	-	SIGNIFICANT	FEASIBLE	YES
FOSSIL RESOURCES DEPLETION	Reduced fossil resources depletion from decreased electricity consumption and generation of national grid	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased fossil resources depletion from increased production, transport, waste processing, disposal of PV panels	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
WASTE GENERATION AND DISPOSAL	Increased waste generation and disposal of PV panels	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	NOT FEASIBLE	PARTLY
RENEWABLE ENERGY GENERATION	Increased renewable energy generation from PV panels	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
RENEWABLE ENERGY SHARE	Increased share of renewable energy from PV panels	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
HEALTH AND SAFETY OCCUPATIONAL RISKS	Increased health and safety conditions for workers in electricity generation of national grid	IN	POSSIBLE	MINOR	+	NOT SIGNIFICANT	N/A	NO

Table 17 (continued)

IMPACT CATEGORIES	SPECIFIC IMPACTS	IN- OR OUT-OF-JURISDICTION	LIKELIHOOD	MAGNITUDE	POSITIVE OR NEGATIVE IMPACT	SIGNIFICANCE	FEASIBILITY TO QUANTIFY	INCLUSION IN QUANTITATIVE ASSESSMENT BOUNDARY
HEALTH AND SAFETY OCCUPATIONAL RISKS (CONTINUED)	Risks of decreased health and safety conditions for workers from PV panels manufacturing and raw material extraction sector	OUT	POSSIBLE	MINOR	-	NOT SIGNIFICANT	N/A	NO
	Risks of decreased health and safety conditions for workers from PV panels waste processing and disposal sector	IN	POSSIBLE	MINOR	-	NOT SIGNIFICANT	NOT FEASIBLE	NO
TRAINING	Decreased training of local skilled workers from national grid electricity generation	IN	UNLIKELY	MINOR	-	NOT SIGNIFICANT	N/A	NO
	Increased training of local skilled workers from PV panels installation	IN	VERY LIKELY	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased training of skilled workers from PV panels manufacturing	OUT	LIKELY	MINOR	-	NOT SIGNIFICANT	N/A	NO
CLIMATE CHANGE AWARENESS	Increased climate change awareness of civil servants	IN	LIKELY	MAJOR	+	SIGNIFICANT	NOT FEASIBLE	NO
LOCAL R&D	Increased local R&D related to energy	IN	POSSIBLE	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
PUBLIC ACCEPTANCE OF RENEWABLES & ENERGY EFFICIENT TECHNOLOGIES	Increased acceptance of renewable energy and energy efficient technologies from potential investors	IN	LIKELY	MAJOR	+	SIGNIFICANT	NOT FEASIBLE	NO
	Increased acceptance of renewable energy and energy efficient technologies from general public	IN	POSSIBLE	MODERATE	+	SIGNIFICANT	NOT FEASIBLE	NO
JOBS	Decreased local jobs from national grid electricity generation	IN	LIKELY	MINOR	-	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased jobs from PV panels production	OUT	LIKELY	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased jobs from PV panels transport	IN/OUT	UNLIKELY	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased jobs from PV panels waste processing	IN	LIKELY	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased local jobs from PV panels installation	IN	POSSIBLE	MODERATE	+	SIGNIFICANT	NOT FEASIBLE	NO
LOCAL ECONOMY	Increased income for the local economy (PV panels supplier)	IN	VERY LIKELY	MAJOR	+	SIGNIFICANT	NOT FEASIBLE	NO
COST SAVINGS	Increased electricity cost savings from PV panels	IN	VERY LIKELY	MAJOR	+	SIGNIFICANT	FEASIBLE	YES
PAYBACK PERIOD	Time in which the PV panels' initial investment pays back	IN	VERY LIKELY	MAJOR	N/A	SIGNIFICANT	FEASIBLE	YES
POLICY COST - EFFECTIVENESS	Ratio of costs to effectiveness for reduction of GHGs and electricity consumption	IN	VERY LIKELY	MAJOR	N/A	SIGNIFICANT	FEASIBLE	YES
REBOUND EFFECTS	Increased rebound effects that impact sustainable development	IN	LIKELY	MODERATE	-	SIGNIFICANT	NOT FEASIBLE	NO

- SOCIAL IMPACTS

Social impacts caused by the climate actions assessed in this thesis were divided into two categories: climate change awareness of civil servants (working in the retrofitted building), and public acceptance of energy retrofit actions.

(I) CLIMATE CHANGE AWARENESS OF CIVIL SERVANTS

In 2015, an internal climate change awareness-raising campaign was launched by the SEPAF supporting the climate actions implemented in the retrofitted building in accordance with the Carbon Management Plan. The objective of this awareness campaign was to help civil servants better understand climate change and energy efficiency, identify actions with negative environmental impacts (mostly related to climate change), and promote simple recommendations civil servants could follow to reduce electricity consumption and decrease the building's carbon footprint. Furthermore, this awareness campaign was designed in a way that climate actions such as the installation of PV panels and LED lamps were shown as main examples portraying the efforts underwent by the ministry.

Following the Carbon Management Plan, the awareness-raising campaign was structured as follows:

- Monthly workshops focused on climate change awareness with staff (civil servants);
- Bimonthly newsletters focused on advertising the campaign;
- Short documentaries produced by the Radio and Television System of Jalisco (*Sistema Jaliciense de Radio y Televisión*) focused on health effects caused by GHG as well as mitigation actions;
- Banners and other posters (printed and digital) focused on advertising the campaign.

Based on the Carbon Management Plan, the climate change awareness raising campaign resulted in an extra 1% of the total CO_2 emissions reductions and electricity cost savings, in the building, achieved by the implemented climate actions (i.e. PV panels and LED lamps). However, no other impact related to the behavioural change of civil servants was possible to determine.

(II) PUBLIC (SOCIO-POLITICAL) ACCEPTANCE OF ENERGY RETROFITS

Public (socio-political) acceptance of energy retrofits was identified as a significant impact of the actions assessed in this thesis. During the specific impacts identification stage, stakeholders referred to two different impacts encompassed by the concept: (i) public acceptance of energy retrofits in public buildings by potential investors of other climate actions within the Carbon Management Plan; and (ii) public acceptance of energy retrofits by public at large (from the State of Jalisco).

As described in Chapter 3, Mallett (2007) uses Rogers (2003) "Innovation-Decision Process" model to define social acceptance in an active manner. The concept is used to describe social acceptance as the adoption of a technology instead of the intention to use a technology. Following this "Innovation-Decision Process" model, social acceptance consists of five stages: (i) knowledge; (ii) persuasion; (iii) decision; (iv) implementation; and (v) confirmation.

Regarding the public acceptance of energy retrofits by potential investors of other climate actions within the Carbon Management Plan, Carbon Trust has used the results of this pilot project in the SEPAF building, which in turn lead to the implementation of other climate actions, to define a second outcome where public-private partnerships will be established in order to finance more climate actions within the policy. These partnerships are currently been pursued in order to achieve the entirety of the 96 project included in the Carbon Management Plan, thus they are located in Roger's (2003) second stage; persuasion. Furthermore, the partnerships will help overcome financial barriers faced by the government by presenting private actors the technical feasibility and GHG emissions reduction potential of climate actions such as the installation of PV panels and LED lamps in public buildings.

Social acceptance by the public at large from the State of Jalisco was also identified as an impact since several state-wide newspapers covered the story of energy retrofits in public buildings (Del Castillo, 2014; Martínez, 2014; Notimex, 2014; El Informador, 2018; Navarro, 2018). However, no information on how the public reacted was found nor how it affected public acceptance of this type of low carbon energy projects. Nevertheless, Rogers (2003) asserts that 'media coverage of an innovative project can shape public acceptance' (p.772). The latter suggests that this coverage represents an impact which should be further analysed, as it will be discussed in Chapter 5.

- ECONOMIC IMPACTS

Economic impacts considered significant in Table 17 include: (i) cost savings ; (ii) jobs; (iii) local economy; and (iv) rebound effects. The latter three impacts are further described in a qualitative manner.

(I) JOBS

Employment in the photovoltaics industry concerns a multiplicity of jobs associated with different phases in the life cycle of the systems. These phases include jobs related to research and development, manufacturing, construction and operations, installation, and recycling (Bakhiyi, Labrèche and Zayed, 2014). In terms of the first climate action (PV panels), the impacts on jobs creation in the raw material extraction, manufacturing, transport, and recycling phases were not considered significant due to the size of the project. However, local jobs related to installation and distribution of PV panels were deemed significant.

As reported by the PV panel supplier no new jobs were created as a result of the governmental contract for the building assessed in this thesis. The supplier estimated that only projects over 300kWp would need additional staff. However, a total of 145 person-hours (man-hours) were spent on the project. Of these 145 person-hours, 10 were spent by sales representatives, 15 by the field engineer, and 120 by skilled installation workers. The average wages of these workers was not possible to estimate, nor a disaggregation of data based on gender.

(II) LOCAL ECONOMY

Various positive impacts were identified with regard to the economy of Jalisco. The contract between the government of Jalisco and the PV panel supplier generated 2% to 3% of the company's annual income in 2014. Furthermore, a favourable public image of the PV supplier, as an effect of the contract, was also identified as a positive impact. An analysis of the local procurement act uncovered other positive impacts on the local economy. The Governmental Procurement, Disposals, and Services Act (*Ley de Compras Gubernamentales, Enajenaciones* *y Contratación de Servicios del Estado de Jalisco y sus Municipios*) (Gobierno del Estado de Jalisco, 2017) gives preference to local (state) suppliers over national ones, as well as preference of national suppliers over international ones. Furthermore, it states that at least 80% of the services contracted by the government must be local. From which, 10% of the services must come from start-up companies (Ibid.).

However, negative impacts were also identified. As reported by the PV supplier, payment times are commonly longer with governmental contracts, compared to private ones. Thus, prices of services and products offered to the government are not the most economical. The increase in those prices is used as a buffer to compensate for the long payment times. In a broader context, this constraint indirectly excludes smaller companies without the financial liquidity needed to endure these long periods of time without receiving any payment for the services provided.

(III) REBOUND EFFECTS

Rebound effects 'encompasses both the behavioral and systems responses to cost reductions of energy services as a result of energy efficiency measures' (Hertwich, 2005, p. 85). With regard to rebound effects from the cost savings generated by the assessed climate actions in this thesis, the author was unable to determine how the money was spent due to lack of data as well as lack of access to suitable tracking systems. Accordingly, a literature review was carried out to determine whether rebound effects should be considered an impact on sustainable development from the aforementioned climate actions.

Otelin et al. (2018) focus on the environmental impacts caused by public spending. However, this study was performed in the context of welfare states, specifically Finland. Welfare states are known for their effective provision of public services funded by the states, through taxation. Another study by Wiedmann and Barrett (2011) determines the carbon footprint of the main GHG emitting sources across the United Kingdom government, paying a special attention to the GHG emissions of procurement along the supply chain. However, none of the studies examine how savings generated by climate policies are spent nor their impacts on sustainable development. Nevertheless, the studies explore public spending as a whole, which is greater than public spending derived from savings, concluding that it is an area in need of further analysis and reporting.

Although the studies focus on countries different from Mexico, they demonstrate that increasing attention is being paid to the sustainable development impacts of public spending. Added to the seldom use of sustainable development impact assessments in current public procurement policies in the State of Jalisco, rebound investments represent a highly possible negative impact of this policy.

4.4.4 Quantitative assessment

- ENVIRONMENTAL IMPACTS

Based on the qualitative assessment, where information from peer-reviewed articles as well as the stakeholder consultation determined the significance and feasibility to quantify specific impacts, the following nine specific environmental impacts were assessed quantitatively: (i) GHG emissions; (ii) depletion of mineral resources; (iii) depletion of fossil resources; (iv) freshwater consumption; (v) land use; (vi) air quality; (vii) human toxicity; (viii) water ecotoxicity; and (ix) renewable energy.

Each of these specific impacts was analysed in the following manner: first, a baseline scenario for the selected period of time (30 years) was estimated, followed by a policy scenario. Then, the net impact was calculated by subtracting the policy scenario values from those of the baseline scenario. These steps were also followed to calculate the current net impact from 2014 to 2018 (5 years). Table 18 shows the net impacts both calculated for 5 and 30 years. It should be noted that for every category with the exception of renewable energy, the impacts caused by the raw materials extraction, production, and transport of the PV panels were only included in the year 2014 when these stages are assumed to have happened. Similarly, impacts from the aluminium frame recycling used to support the PV panels were included in the year 2043, when this is assumed to take place. Table 18 also shows that the policy scenario only has a positive effect on three of the nine categories, if analysed from the date of installation to the present day (i.e. 5 years). However, all categories have a positive impact over the entire lifespan of the PV panels (i.e. 30 years), even if the early stages of the PV panels (raw material extraction, production, and transport) are considered.

Table 18 Summary of environmental impacts generated by Climate Action 1 - PV panels. Net impacts are calculated for 5 years (2014-2018) and 30 years (2014-2043).

IMPACT	UNIT	BASELINE SCENARIO (5 yrs)	POLICY SCENARIO (5 yrs)	NET IMPACT (5 yrs)	% NET IMPACT (5 yrs)	BASELINE SCENARIO (30 yrs)	POLICY SCENARIO (30 yrs)	NET IMPACT (30 yrs)	% NET IMPACT (30 yrs)
GHG EMISSIONS	t CO_2 eq	812	770	**42**	**5%**	3,637	3,425	**212**	**6%**
DEPLETION OF MINERAL RESOURCES	kg Cu eq	220	277	**-57**	**-26%**	1,701	1,659	**42**	**2%**
DEPLETION OF FOSSIL RESOURCES	kg oil eq	254,759	241,162	**13,597**	**5%**	1,136,319	1,069,636	**66,683**	**6%**
FRESHWATER CONSUMPTION	m^3	1,798	1,906	**-108**	**-6%**	10,113	9,718	**395**	**4%**
LAND USE	m^2a crop eq	1,439	1,535	**-96**	**-7%**	29,748	28,136	**1,612**	**5%**
AIR QUALITY	DALY	0.84	0.80	**0.04**	**5%**	3.1	2.9	**0.2**	**6%**
HUMAN TOXICITY	DALY	0.087	0.088	**-0.001**	**-1%**	0.46	0.44	**0.02**	**5%**

Table 18 (continued)

IMPACT	UNIT	BASELINE SCENARIO (5 yrs)	POLICY SCENARIO (5 yrs)	NET IMPACT (5 yrs)	% NET IMPACT (5 yrs)	BASELINE SCENARIO (30 yrs)	POLICY SCENARIO (30 yrs)	NET IMPACT (30 yrs)	% NET IMPACT (30 yrs)
WATER ECOTOXICITY	kg 1,4-DCB	21,484	24,135	**-2,651**	**-12%**	135,574	131,333	**4,241**	**3%**
RENEWABLE ENERGY CONSUMPTION	kWh	187,140	257,207	**70,067**	**37%**	2,341,200	2,780,042	**438,842**	**19%**
RENEWABLE ENERGY SHARE (%)	N/A	14%	20%	**6%**	**-**	30%	36%	**6%**	**-**

The assessed impact categories, with the exception of renewable energy, can be broadly separated into two groups. In the first group, the policy scenario has positive impacts compared to the baseline scenario if analysed from 2014 to 2018 (i.e. 5 years) as well as from 2014 to 2043 (i.e. 30 years). An example of this is shown in Figure 14 which presents the results for GHG emissions impacts. This is also the case for depletion of fossil resources as well as air quality (figures presenting the results are found in Appendix 6).

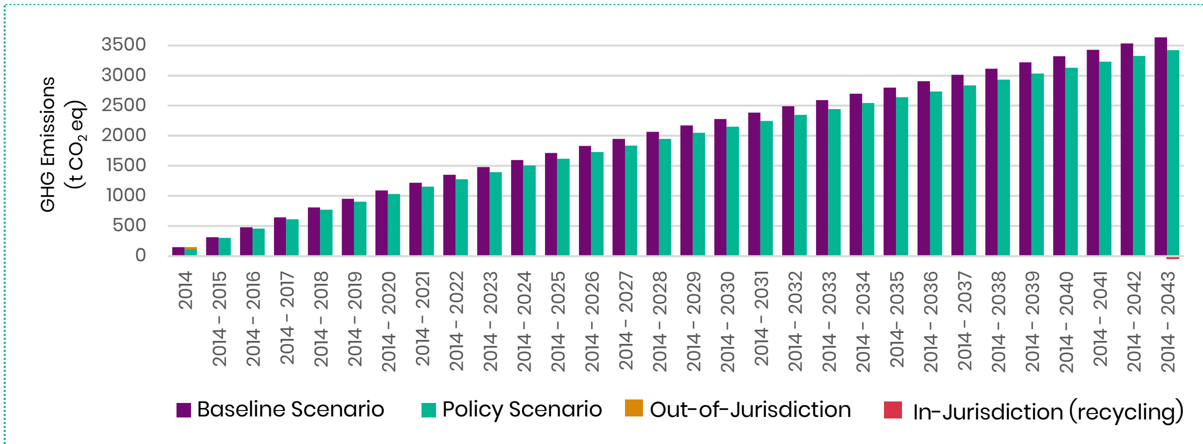

Figure 14 Accumulated GHG emissions impacts of Climate Action 1 – PV Panels. Production impacts from PV panels are included in 2014 and disposal impacts in 2043.

In the second group, the remaining categories have a positive net impact over their entire lifespan (i.e. 30 years). However, if analysed only from 2014 to 2018 (i.e. 5 years), the policy scenario results in negative impacts compared to the baseline scenario. Examples of this situation are shown in Figure 15 and Figure 16, which present the results for depletion of mineral resources impacts and water ecotoxicity impacts, respectively. As can be observed from Figure 15, the policy scenario initially causes negative effects compared to the baseline scenario from 2014 to 2035. These negative impacts are mostly attributed to the metallisation paste containing silver in the production of solar cells (Jungbluth et al., 2012). However, as can be noted in this same figure, the negative trend will change over time before the 30 years lifetime of the PV panels are reached, specifically in 2036. Similar to these impacts on mineral resources usage,

Figure 16 shows the results for water ecotoxicity impacts. As seen in Figure 16, the policy scenario results in net negative impacts from 2014 to 2028; however, from 2029 onwards, the policy scenario presents positive net impacts. The years when the policy scenario will become beneficial for the remaining categories are as follows: freshwater consumption will reach this point in 2024, land use in 2021, and human toxicity in 2020. Furthermore, figures presenting the results of these latter categories are found in Appendix 6.

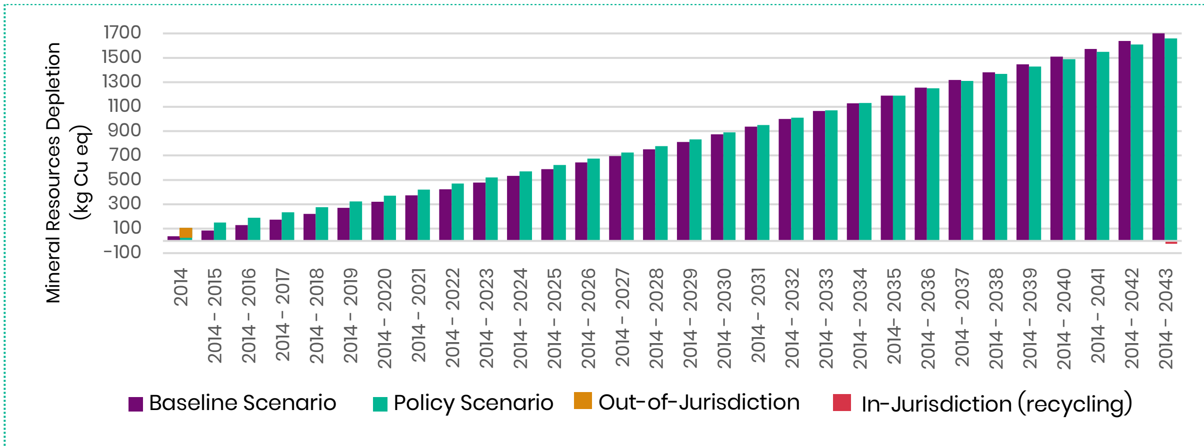

Figure 15 Accumulated mineral resources depletion impacts of Climate Action 1 – PV Panels. Production impacts from PV panels are included in 2014 and disposal impacts in 2043.

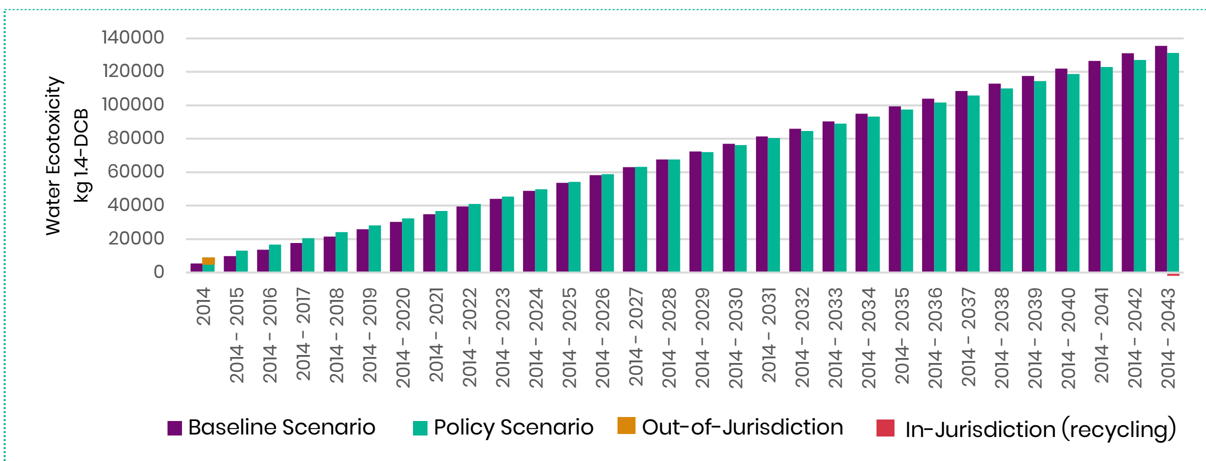

Figure 16 Accumulated water ecotoxicity impacts of Climate Action 1 - PV panels. Production impacts from PV panels are included in 2014 and disposal impacts in 2043.

Figures 15 and 16 also show the in-jurisdiction and out-of-jurisdiction impacts attributed solely to the PV panels in the policy scenario. On the one hand, out-of-jurisdiction impacts are those generated by the raw materials extraction, manufacturing, and transport of the PV panels, which are assumed to have happened outside of Mexico. These types of impacts are coloured in yellow in the aforementioned figures. On the other hand, in-jurisdiction impacts from the PV panels are constituted by the recycling of the aluminium frame used to support the panels. These latter effects, which are coloured in red in the figures, are beneficial to the policy scenario since the recycling partly offsets the negative impacts caused by the production of the panels. Table 19 present the in-jurisdiction and out-of-jurisdiction impacts generated by the PV panels alone.

Table 19 Summary of PV panels life cycle environmental impacts categorised by in-jurisdiction and out-of-jurisdiction impacts.

IMPACT	UNIT	TOTAL IMPACT	OUT-OF-JURISDICTION IMPACTS (raw materials extraction, manufacturing & transport)	IN-JURISDICTION IMPACTS (recycling)
GHG EMISSIONS	t CO^2 eq	5.9	6.9	-1
DEPLETION OF MINERAL RESOURCES	kg Cu eq	60.3	70.2	-9.9
DEPLETION OF FOSSIL RESOURCES	kg oil eq	1,528.5	1,723.9	-195.4
WATER CONSUMPTION	m^3	210.6	215.6	-5
LAND USE	m^2a crop eq	173.1	182.7	-9.6
AIR QUALITY	DALY	0.009	0.010	-0.001
HUMAN TOXICITY	DALY	0.005	0.006	-0.001
WATER ECOTOXICITY	kg 1,4-DCB	3,900.2	3,947.4	-47.2

In regard to renewable energy consumption, it can be seen from Table 18 that the baseline scenario (30 years) amounts to 2,216,393 kWh. This consumption derives from the primary renewable energy sources used in the national electricity mix (i.e. hydroelectric, wind, geothermal, photovoltaics, bioenergy, and cogeneration) and its contribution. In contrast, a total of 2,655,235 kWh were consumed from renewable energy sources in the policy scenario. The positive net impact results solely from the installation of PV panels.

- ECONOMIC IMPACTS

Following the results from the qualitative assessment, the following specific impacts were assessed quantitatively: (i) electricity savings and (ii) cost savings. Furthermore, indicators such as SPB, NPV, and policy cost-effectiveness were also estimated. Table 20 summarises the impacts and indicators calculated for the first climate action; installation of PV panels. It can be observed that these panels generated electricity savings of over 70,000 kWh from 2014 to 2018 (i.e. 5 years). Hence, generating cost savings of over MX$ 130,000 in the same period. These electricity savings are expected to increase up to 438,842 kWh representing MX$1,039,980 from 2014 to 2043 (i.e. 30 years). In order to determine the profitability of this first retrofit, SPB and NPV were calculated. As can be seen from Table 20, payback time of the PV panels is 21.3 years, hence the investment is considered economically justifiable since it does not exceed the time scale of calculations (30 years). Similarly, the NPV is a positive figure, demonstrating that the cost savings generated over the lifetime of the PV panels pay off the initial investment.

In terms of policy cost-effectiveness, the indicator was only calculated using the period of time that equals the lifetime of the PV panels (i.e. 30 years), since it is a fairer option to describe the impact of this indicator. Policy cost-effectiveness of the PV panels was estimated to be 2,931

Mexican Pesos per tCO_2 mitigated. It is important to note, that these cost-effectiveness calculations assume changes in the electricity mix, thus, the amount of CO_2 mitigated values during the assessed period varies. However, no replacements were assumed.

Table 20 Summary of economic impacts generated by Climate Action 1 - PV panels. Net impacts are calculated for 5 years (2014-2018) and 30 years (2014-2043).

ECONOMIC INDICATOR	UNIT	BASELINE SCENARIO	POLICY SCENARIO	NET IMPACT
TOTAL INVESTMENT COSTS (year 1 - 2014)	MX$	N/A	N/A	622,841
REAL SOCIAL DISCOUNT RATE	N/A	N/A	N/A	3.3%
ELECTRICITY PRICE INCREASE RATE	N/A	N/A	N/A	3%
COST SAVINGS (year 1 - 2014)	MX$	N/A	N/A	29,190
ELECTRICITY SAVINGS (5 years)	kWh	0	70,067	70,067
COST SAVINGS (5 years)	MX$	0	137,569	137,569
ELECTRICITY SAVINGS (30 years)	kWh	0	438,842	438,842
COST SAVINGS (30 years)	MX$	0	1,039,980	1,039,980
SPB	yrs	N/A	21.3	N/A
NPV (30 years)	MX$	N/A	417,139	N/A
COST EFFECTIVENESS	MX$/$tCO_2$	N/A	2,931	N/A

4.4.5 Uncertainty and sensitivity analyses

Both quantitative assessments contain uncertainties, which must be noted and further assessed with the help of sensitivity analyses. These analyses are performed when uncertainty exists for key parameters used in assessments and involve changing one or more of the selected key parameters in order to recalculate and compare the different results.

With regard to the environmental analysis, although the database used for the environmental assessment, namely, the Ecoinvent v4.3 database (Wernet *et al.*, 2016), is currently one of the most well-known and comprehensive databases, the assessment contains uncertainty due to the lack of location-specific data as well as the selection of global average values for the model. Moreover, the existing process in the Ecoinvent v3.4 database for PV panels assumed that the manufacturer performs the waste processing and disposal operations, following an extended producer responsibility policy (Sica *et al.*, 2018). However, this type of environmental policy has not been adopted in Mexico. Furthermore, there is a lack of a formal plan stated in the Carbon Management Plan for these disposal and recycling operations. However, since data needed to model a context-specific waste process was not available, it was not possible to quantify this parameter and include it in the sensitivity analysis. The only process within the end-of-life stage possible to quantify was the recycling of aluminium for the PV panels mounting. Thus, an environmental sensitivity analysis was performed, where the results from the assessment (recycling of aluminium is assumed) are compared to a scenario where this metal does not undergo any type of recycling. Table 21 present the results of this environmental sensitivity analysis, where it can be observed that six out of eight environmental impacts are negatively affected if recycling of aluminium is not pursued after the PV panels reach the end of their lifespan.

Table 21 Environmental sensitivity analysis - Recycling of metals in Climate Action 1 - PV Panels.

SPECIFIC IMPACT	UNIT	NET IMPACTS – RECYCLING OF ALUMINIUM (POLICY SCENARIO)	NET IMPACTS – NO RECYCLING OF METALS
GHG EMISSIONS	t CO^{2} eq	212	211
DEPLETION OF MINERAL RESOURCES	kg Cu eq	42	32
DEPLETION OF FOSSIL RESOURCES	kg oil eq	66,683	66,487
WATER CONSUMPTION	m^3	395	391
LAND USE	m^2a crop eq	1,612	1,602
AIR QUALITY	DALY	0.2	0.2
HUMAN TOXICITY	DALY	0.02	0.02
WATER ECOTOXICITY	kg 1,4-DCB	4,241	4,194

In regard to the economic assessment, three sensitivity analyses were performed, where the real social discount rate and the actual electricity price increase rate were changed in order to analyse how sensitive the economic results were to these two rates. A "high" real social discount rate was selected (6%) based on recommendations given by an analysis from the World Bank (Lopez, 2008). Similarly, a "high" electricity price increase rate (10%) was selected based on recommendations and practical examples given by expert staff from Carbon Trust Mexico and the UNEP-DTU Partnership. From these economic analyses, it can be seen that the electricity increase rate is the parameter that mostly affects the results. It can also be inferred that economic benefits derived from the first climate action will grow if electricity prices increase at a rate higher than 3% in the following 24 years.

Table 22 Economic sensitivity analysis – Rates used in Climate Action 1 - PV Panels.

OPTION	COMBINATION OF RATES	RATE	UNIT	COST SAVINGS (30 years)	NPV
OPTION 1 (POLICY SCENARIO)	LOW Social Discount Rate	3.3%	MX$	1,039,980	417,139
	LOW Electricity Price Increase Rate	3%			
OPTION 2	LOW Social Discount Rate	3.3%	MX$	2,483,089	1,860,248
	HIGH Electricity Price Increase Rate	10%			
OPTION 3	HIGH Social Discount Rate	6%	MX$	796,598	173,757
	LOW Electricity Price Increase Rate	3%			
OPTION 4	HIGH Social Discount Rate	6%	MX$	1,708,805	1,085,964
	HIGH Electricity Price Increase Rate	10%			

4.5 Climate action 5 – LED lamps

This section presents the second climate action of the case study where 373 fluorescent luminaires were substituted with 340 LED luminaires in the SEPAF building in 2014.

4.5.1 Baseline scenario

In the baseline scenario, it was assumed that 373 luminaires (746 lamps) were replaced by the same number of newer versions of fluorescent lamps (FLs). Thus, the functional unit for the second climate action is the total amount of lamps (746) used in the SEPAF building. This amounts to 2831 hours per year for 17.6 years (April 2014 – December 2031). It was assumed that the investment costs for these lamps amounted to MX$124,589. This estimation was based on a market study performed by the Ministry of Energy (SENER) (Mexico. SENER, 2015).

Based on information provided by the SEMADET, the SEPAF building had 13 different types of luminaires installed. Most of these luminaires consisted of a metal housing, a ballast, and two FLs. In the model used for the present thesis, it is assumed that the three types originally corresponding to 72% of the total luminaires, represent the 100% of the luminaires in a proportionate manner. The selected types are the following: (i) fluorescent tubular U-bent T8 64W (consisting of two 32W lamps) for dropped ceilings; (ii) fluorescent tubular U-bent T8 118W (consisting of two 59W lamps) for dropped ceilings; and (iii) fluorescent tubular linear T5 45W (consisting of two 21W lamps). It is assumed that no new housings, fixtures nor ballasts were installed, thus, the retrofit action only included the change of lamps.

Figure 17 presents a simplified flowchart including the system boundaries used to environmentally assess the FLs changed in the SEPAF building. These lamps are assumed to be produced in mainland China, whose production, in 2011, accounted for more than 80% of the global production (Xin *et al.,* 2012 cited in Chen, Zhang and Kim, 2017, p.468) A separation of in-jurisdiction and out-of-jurisdiction stages are depicted in the aforementioned figure. Both the social and the economic assessment only focused on the use phase.

Data concerning the assumptions made for the different life cycle stages of the lamps is presented in Table 23. The use stage was calculated based on ministerial accounting records provided by SEMADET, which accounts for a total of 80077.4 kWh consumed annually by the 746 fluorescent lamps. A total of 260 working days a year, 10.89 hours a day, and 2831 hours a year were assumed in order to match the electricity consumption and the selected lamp types. Furthermore, it was assumed that the waste processing and disposal stages of the lamps were done in a manual treatment facility for waste electric and electronic equipment (WEEE) devices.

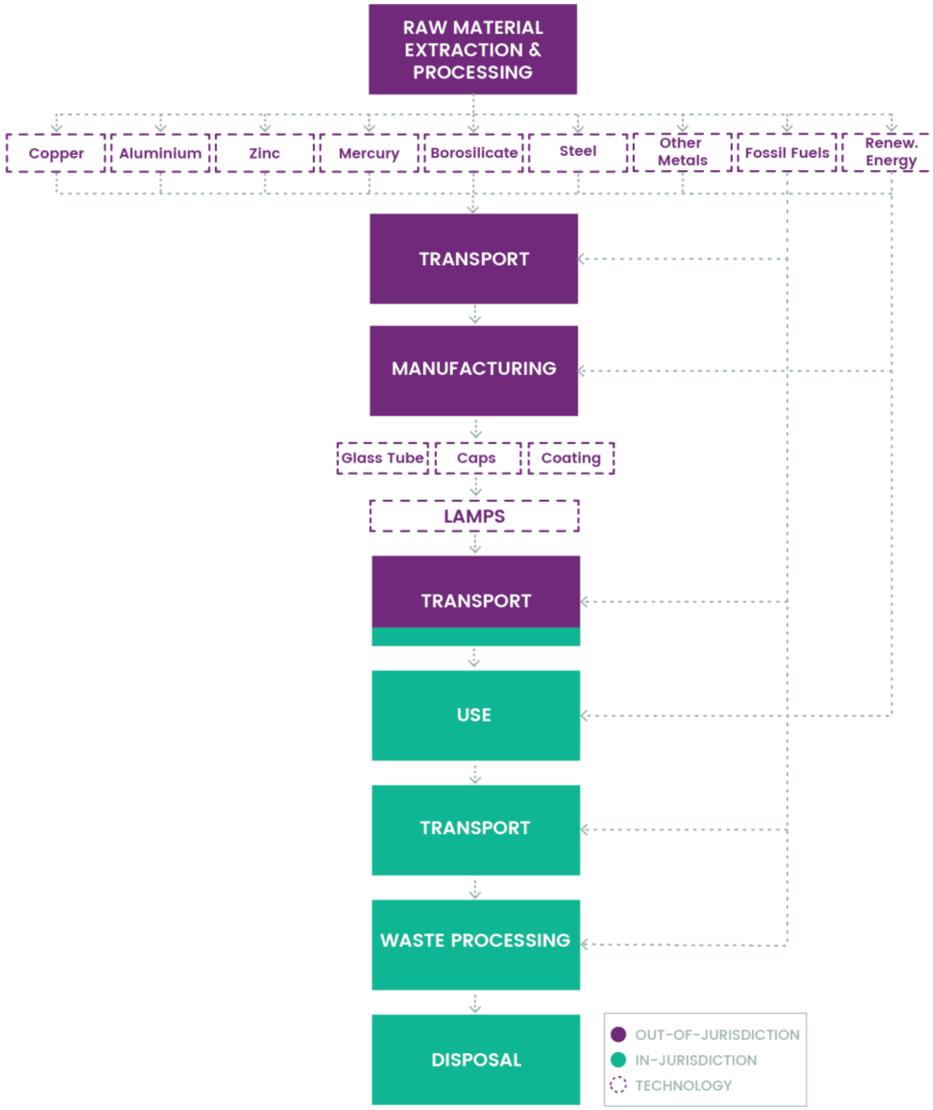

Figure 17 Simplified flowchart with system boundaries of FL lamps in the SEPAF building.

Table 23 also presents the inventory data needed for the production of each of the lamps. Whilst the materials and processes were taken from the Ecoinvent v3.4 database, quantities of these materials and processes were adapted from Navigant Consulting Europe (2009) and Tähkämö *et al.* (2014) based on the dimensions of the selected lamps. The packaging of the lamps and energy used to assemble them are not included in the LCA model. Whilst sea distances for the transport stage were calculated from (Sea Distances, N.D.), land distances were calculated from (Transportica, N.D.).

Table 23 Assumptions used for modelling the baseline scenario of fluorescent lamps. Based on ministerial accounting records and (Navigant Consulting Europe, 2009; Tähkämö et al., 2014; Sea Distances, N.D.; Transportica, N.D.).

TYPE OF ASSUMPTIONS	INPUT	T8 32W	T8 59W	T5 21W
GENERAL	QUANTITY OF LAMPS INSTALLED IN BUILDING	256	258	232
	LIFETIME (YEARS)	20,000	20,000	20,000
	TOTAL CONSUMPTION IN 1 YEAR (kWh)	23,195	43,100	13,795
MATERIALS (PER LAMP)	GLASS TUBE, BOROSILICATE (kg) - Tube	0.1493	0.1493	0.0929
	ALUMINIUM, CAST ALLOY (kg) - Caps	0.0048	0.0048	0.003
	MERCURY (kg)	0.000010	0.000010	0.000004
	ARGON, LIQUID (kg)	0.0010	0.0010	0.0004
	RARE EARTH CONCENTRATE, 70% REO, FROM BASTNASITE (kg) – Phosphor coating	0.0032	0.0032	0.0020
PROCESSES (PER LAMP)	SHEET ROLLING, ALUMINIUM (kg) - Caps	0.0048	0.0048	0.0030
TRANSPORT (PER LAMP)	TRANSPORT, FREIGHT, SEA, TRANSOCEANIC SHIP (tkm) – From Shenzhen to Manzanillo	1.3790	2.2224	2.2224
	TRANSPORT, FREIGHT, LORRY (tkm) - From Manzanillo to Guadalajara	0.0287	0.0462	0.0462
	TRANSPORT, FREIGHT, LORRY (tkm) – From SEPAF building to WEEE facility	0.0039	0.0063	0.0063
DISPOSAL (PER KG)	MANUAL TREATMENT FACILITY, WASTE ELECTRIC AND ELECTRONIC EQUIPMENT (pieces)	8.0E-10	8.0E-10	8.0E-10
	ELECTRICITY, MEDIUM VOLTAGE (kWh)	0.03	0.03	0.03

4.5.2 Policy scenario

Whilst in the baseline scenario it was assumed that 373 luminaires (746 lamps) were replaced by the same number of newer versions of FLs, the policy scenario describes the observed retrofitting action of installing 340 Light Emitting Diode (LED) luminaires (800 lamps) in the SEPAF building. In order to properly compare these two scenarios, the functional unit used to assess them remained the same: the total amount of lamps (800) used in the SEPAF building. This amounts to 2831 hours per year for 17.6 years (April 2014 – December 2031).

Based on information provided by SEMADET, the SEPAF building installed 5 different models of luminaires. However, the quantities and the criteria used to replace the FLs with the LED luminaires was not provided. Based on the total annual consumption by the 800 lamps of 44450.3 kWh as well as pictures from the retrofit provided by the SEMADET, it was assumed that the following 3 models were installed: (i) LED 2X14W (consisting of two 14W lamps) for dropped ceilings; (ii) LED 3X14W (consisting of three 14W lamps) for dropped ceilings; and (iii) LED 2X28W (consisting of two 28W lamps). It was assumed that no new housings nor fixtures were installed, thus, the retrofit action only included the change of lamps.

Figure 18 describes the system boundaries used to assess the LED lamps changed in the SEPAF building. These lamps were assumed to be produced in mainland China. In-jurisdiction and out-of-jurisdiction stages are separated in the aforementioned figure. Following the policy scenario described for the PV panels, the social and economic assessment of the LED lamps only focused on a specific stage from the system boundaries presented. This stage is the use of the LED lamps. Furthermore, socio-economic impacts were only analysed locally and the cost savings impacts were analysed from the point of view of the government of Jalisco, as the owner of the buildings.

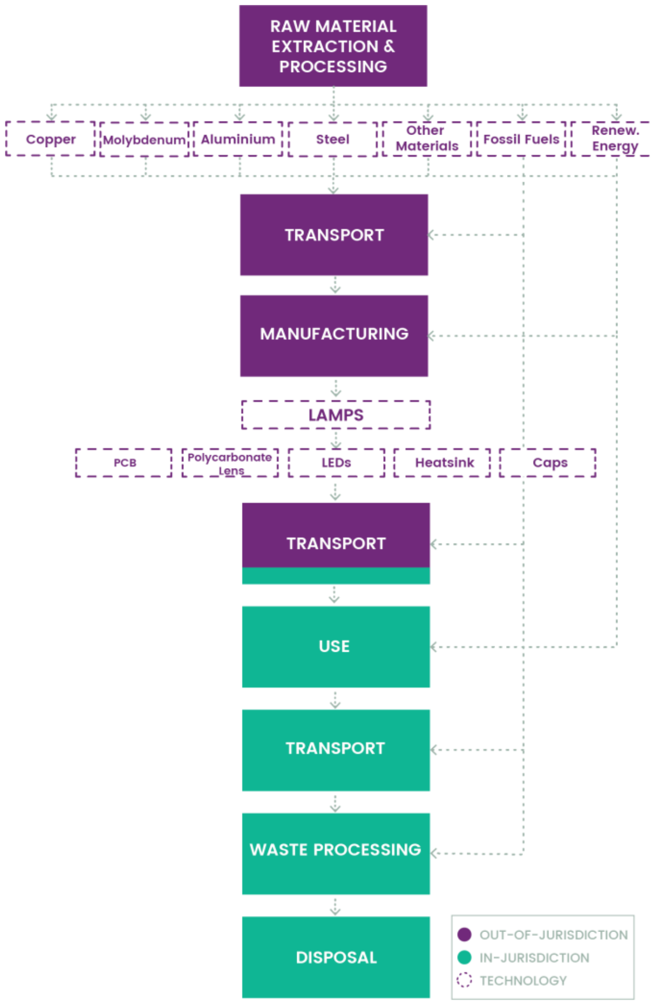

Figure 18 Simplified flowchart with system boundaries of LED lamps in the SEPAF building.

Data concerning the assumptions made for the different stage of the lamps life cycle is presented in Table 24. The use stage was calculated based on the annual electricity consumption of the 800 LED lamps. A total of 260 working days a year, 10.89 hours a day, and 2831 hours a year were assumed in order to match the electricity consumption and the selected lamp types. Furthermore, it was assumed that the waste processing and disposal stages of the lamps were done in a manual treatment facility for waste electric and electronic equipment (WEEE) devices. Other key parameters used in the economic assessment, conducted from the perspective of the government of Jalisco, include the total investment costs of the LED lamps and the real discount rate. The total investment costs were MX$177,698.00 and only include the purchase of the lamps. The investment costs were found in internal ministerial records and progress reports provided by the SEMADET, thus, no uncertainty related to these values are assumed.

Table 24 also presents the inventory data needed for the production of each of the lamps. Since no previous LCA nor inventory data for LED tube lamps was found, the materials and processes to model these lamps were based on general information from Navigant Consulting Europe (2009) and Tähkämö *et al.*(2013), a detailed video of the production of these lamps from the manufacturer Independence LED (Independence LED, N.D.) as well as standard dimensions for aluminium and polycarbonate profiles. The packaging of the lamps and energy used to assemble them are not included in the LCA model. Whilst sea distances for the transport stage were calculated from (Sea Distances, N.D.), land distances were calculated from (Transportica, N.D.).

Table 24 Assumptions used for modeling the policy scenario of LED lamps. Based on ministerial accounting records and (Independence LED, N.D.; Navigant Consulting Europe, 2009; Tähkämö et al.*, 2013; Sea Distances, N.D.; Transportica, N.D.).*

TYPE OF ASSUMPTIONS	INPUT	T8 14W	T8 28W
GENERAL	QUANTITY OF LAMPS INSTALLED IN BUILDING	490	310
	LIFETIME (YEARS)	50,000	50,000
	TOTAL CONSUMPTION IN 1 YEAR (kWh)	19,423	24,577
MATERIALS (PER LAMP)	ALUMINIUM, CAST ALLOY (kg) - PCB	0.0650	0.1300
	LIGHT EMITTING DIODE (kg) – 120 LEDs	0.0420	0.0840
	ALUMINIUM, CAST ALLOY (kg) - Heatsink	0.2340	0.4680
	ALUMINIUM, CAST ALLOY (kg) - Caps	0.0048	0.0010
	POLYCARBONATE (kg) - Lens	0.1040	0.2080
	SOLDER, PASTE, Sn95.5Ag3.9Cu0.6 (kg) - Solder	0.0060	0.0120
PROCESSES (PER LAMP)	METAL WORKING, AVERAGE FOR ALUMINIUM PRODUCT MANUFACTURING - PCB	0.0650	0.1300
	SHEET ROLLING, ALUMINIUM (kg) - Caps	0.0048	0.0048
	SECTION BAR EXTRUSION, ALUMINIUM (kg) - Heatsink	0.2340	0.4680
	EXTRUSION, PLASTIC PIPES (kg) - Lens	0.1040	0.2080
TRANSPORT (PER LAMP)	TRANSPORT, FREIGHT, SEA, TRANSOCEANIC SHIP (tkm) – From Shenzhen to Manzanillo	6.3929	12.7183
	TRANSPORT, FREIGHT, LORRY (tkm) - From Manzanillo to Guadalajara	0.1330	0.2647
	TRANSPORT, FREIGHT, LORRY (tkm) – From SEPAF building to WEEE facility	1.8232E-5	3.6272E-5
DISPOSAL (PER KG)	MANUAL TREATMENT FACILITY, WASTE ELECTRIC AND ELECTRONIC EQUIPMENT (pieces)	8.0E-10	8.0E-10
	ELECTRICITY, MEDIUM VOLTAGE (kWh)	0.03	0.03

4.5.3 Qualitative assessment

Similar to the qualitative assessment performed for the first climate action (i.e. installation of PV panels), the qualitative assessment for the second climate action (i.e. installation of LED lamps) was performed by analysing each of the impacts, presented in Figures 9 to 11, based on their significance. Results of the environmental, social, and economic qualitative assessment are summarised in Table 25. Whilst Table 25 presents the entirety of specific impacts previously identified, this sub-section only discusses the specific impacts classified as significant that were not possible to quantify, thus, not included in the quantitative assessment. Since the totality of specific environmental impacts identified in the case study was included in the quantitative assessment boundary, these impacts are not discussed in the qualitative assessment.

As can be observed in Table 25, the first column contains the impact categories determined as relevant in earlier steps. These impact categories are divided into specific impacts, determined in Figures 9 to 11, and further analysed in order to determine their significance. The nature of the impacts (positive or negative) is also included in this table. As mentioned in sub-section 4.4.3, three specific impacts were considered as significant effects of the two climate actions together. Since a disaggregation of results was not possible, these results are only presented in the aforementioned sub-section. These three specific impacts are: (i) climate change awareness of civil servants (social impact); (ii) increased acceptance of energy retrofit actions (social impact); and (iii) rebound effects (economic impact).

Table 25 Qualitative assessment summary of Climate Action 2 – LED Lamps.

IMPACT CATEGORIES	SPECIFIC IMPACTS	IN- OR OUT-OF-JURISDICTION	LIKELIHOOD	MAGNITUDE	POSITIVE OR NEGATIVE IMPACT	SIGNIFICANCE	FEASIBILITY TO QUANTIFY	INCLUSION IN QUANTITATIVE ASSESSMENT BOUNDARY
GHG EMISSIONS	Reduced GHG emissions from decreased electricity consumption and generation of national grid	IN	VERY LIKELY	MAJOR	+	SIGNIFICANT	FEASIBLE	YES
	Increased GHG emissions from increased production, transport, waste processing, disposal of LED lamps	IN/OUT	VERY LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
AIR QUALITY	Increased air quality from decreased electricity consumption and generation of national grid	IN	POSSIBLE	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Reduced air quality from increased production, transport, waste processing, disposal of LED lamps	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
HUMAN TOXICITY	Reduced human toxicity from decreased electricity consumption and generation of national grid	IN	LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased human toxicity from increased production, transport, waste processing, disposal of LED lamps	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
FRESHWATER CONSUMPTION	Reduced freshwater consumption from decreased electricity consumption and generation of national grid	IN	LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased freshwater consumption from increased production, transport, waste processing, disposal of LED lamps	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
LAND USE	Reduced land use from decreased electricity consumption and generation of national grid	IN	LIKELY	MINOR	+	NOT SIGNIFICANT	N/A	YES
	Increased land use from increased production, transport, waste processing, disposal of LED lamps	IN/OUT	LIKELY	MINOR	-	NOT SIGNIFICANT	N/A	NO
MINERAL RESOURCES DEPLETION	Reduced mineral resources depletion from decreased electricity consumption and generation of national grid	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased mineral resources depletion from increased production, transport, waste processing, disposal of LED lamps	IN/OUT	VERY LIKELY	MAJOR	-	SIGNIFICANT	FEASIBLE	YES
FOSSIL RESOURCES DEPLETION	Reduced fossil resources depletion from decreased electricity consumption and generation of national grid	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	FEASIBLE	YES
	Increased fossil resources depletion from increased production, transport, waste processing, disposal of LED lamps	IN/OUT	LIKELY	MODERATE	-	SIGNIFICANT	FEASIBLE	YES
WASTE GENERATION AND DISPOSAL	Increased waste generation and disposal of LED lamps	IN	VERY LIKELY	MODERATE	+	SIGNIFICANT	NOT FEASIBLE	PARTLY
HEALTH AND SAFETY OCCUPATIONAL RISKS	Increased health and safety conditions for workers in electricity generation of national grid	IN	POSSIBLE	MINOR	+	NOT SIGNIFICANT	N/A	NO
	Risks of decreased health and safety conditions for workers from LED lamps manufacturing and raw material extraction sector	OUT	POSSIBLE	MINOR	-	NOT SIGNIFICANT	N/A	NO
	Risks of decreased health and safety conditions for workers from LED lamps waste processing and disposal sector	IN	POSSIBLE	MINOR	-	NOT SIGNIFICANT	NOT FEASIBLE	NO

Table 25 (continued)

IMPACT CATEGORIES	SPECIFIC IMPACTS	IN- OR OUT-OF-JURISDICTION	LIKELIHOOD	MAGNITUDE	POSITIVE OR NEGATIVE IMPACT	SIGNIFICANCE	FEASIBILITY TO QUANTIFY	INCLUSION IN QUANTITATIVE ASSESSMENT BOUNDARY
TRAINING	Decreased training of local skilled workers from national grid electricity generation	IN	UNLIKELY	MINOR	-	NOT SIGNIFICANT	N/A	NO
	Increased training of skilled workers from PV panels manufacturing	OUT	LIKELY	MINOR	-	NOT SIGNIFICANT	N/A	NO
HUMAN HEALTH	Increased civil servants' human health from better visual conditions and reduced risk to harmful substances from LED lamps	IN	LIKELY	MAJOR	+	SIGNIFICANT	NOT FEASIBLE	NO
CLIMATE CHANGE AWARENESS	Increased climate change awareness of civil servants	IN	LIKELY	MAJOR	+	SIGNIFICANT	NOT FEASIBLE	NO
LOCAL R&D	Increased local R&D related to energy	IN	POSSIBLE	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
PUBLIC ACCEPTANCE OF RENEWABLES & ENERGY EFFICIENT TECHNOLOGIES	Increased acceptance of renewable energy and energy efficient technologies from potential investors	IN	LIKELY	MAJOR	+	SIGNIFICANT	NOT FEASIBLE	NO
	Increased acceptance of renewable energy and energy efficient technologies from general public	IN	POSSIBLE	MODERATE	+	SIGNIFICANT	NOT FEASIBLE	NO
JOBS	Decreased local jobs from national grid electricity generation	IN	LIKELY	MINOR	-	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased jobs from LED lamps production	OUT	LIKELY	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased jobs from LED lamps transport	IN/OUT	UNLIKELY	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
	Increased jobs from LED lamps waste processing	IN	LIKELY	MINOR	+	NOT SIGNIFICANT	NOT FEASIBLE	NO
LOCAL ECONOMY	Increased income for the local economy (LED lamps supplier)	IN	VERY LIKELY	MAJOR	+	SIGNIFICANT	NOT FEASIBLE	NO
COST SAVINGS	Increased electricity cost savings from LED lamps	IN	VERY LIKELY	MAJOR	+	SIGNIFICANT	FEASIBLE	YES
PAYBACK PERIOD	Time in which the LED lamps' initial investment pays back	IN	VERY LIKELY	MAJOR	N/A	SIGNIFICANT	FEASIBLE	YES
POLICY COST - EFFECTIVENESS	Ratio of costs to effectiveness for reduction of GHGs and electricity consumption	IN	VERY LIKELY	MAJOR	N/A	SIGNIFICANT	FEASIBLE	YES
REBOUND EFFECTS	Increased rebound effects that impact sustainable development	IN	LIKELY	MODERATE	-	SIGNIFICANT	NOT FEASIBLE	NO

- SOCIAL IMPACTS

Social impacts considered significant in Table 25 include: (i) climate change awareness; (ii) public acceptance of energy retrofits; and (iii) lighting quality in offices affecting human health. Whilst the latter impact is further explained, the former two impacts are described in sub-section 4.4.3.

(I) LIGHTING QUALITY IN OFFICES

According to internal progress reports, illuminance at a point (on a working plane) measurements were performed for FLs as well as LED lamps. Whilst the latter resulted in an illuminance of 366 lux, the former had an illuminance of 168 lux. Following lighting standards from the Illuminating Engineering Society of North America (IES), where illuminance recommendations for working environments range from 300 to 400 lux (DiLaura, et al., 2011), only LEDs lamps complied with these standards. Hence, LED lamps provide civil servants with visual conditions which allow them to perform visual tasks safely and comfortably.

Furthermore, FLs are associated with health issues during their use stage, which LED lamps are not associated with. Defective tube coatings from FLs can let ultraviolet light escape causing skin and retina damage (Zielinska-Dabkowska, 2018). Moreover, flickering at 100 to 120 hertz from FLs can cause headaches and eyestrain (Wilkins *et al.*, 1989). Thus, the installation of LED lamps resulted in positive impacts on human health of staff working in the building.

- ECONOMIC IMPACTS

Economic impacts considered significant in Table 25 include: (i) cost savings ; (ii) jobs; (iii) local economy; and (iv) rebound effects. The latter impact (i.e. rebound effects) is explained in sub-section 4.4.3.

Although both jobs and local economy were identified as significant specific impacts, it was not possible to locate the LED lamps supplier, thus, no information on new jobs nor the effect of the governmental contract on their finances was obtained. Nevertheless, from the previous analysis of the local procurement act in sub-section 4.4.3, where local suppliers are given a preference over national and international ones, in addition to the start-up's quota of 10%; it can be inferred that there is a positive impact on this category. However, it can also be inferred that governmental payment times to suppliers negatively affect these businesses. Thus, prices of the services and products offered to the government are not the most economical. The increase in those prices is used as a buffer to compensate for the long payment times. In a broader context, this constraint indirectly excludes smaller companies without the financial liquidity needed to endure these long periods of time without any payment for the services provided.

4.5.4 Quantitative assessment

- ENVIRONMENTAL IMPACTS

Based on the qualitative assessment, where information from peer-reviewed articles as well as the stakeholder consultation determined the significance and feasibility to quantify specific impacts, the following eight specific environmental impacts were assessed quantitatively: (i) GHG emissions; (ii) depletion of mineral resources; (iii) depletion of fossil resources; (iv) freshwater consumption; (v) land use; (vi) air quality; (vii) human toxicity; and (viii) water ecotoxicity.

Each of these specific impacts were analysed in the following manner: first, a baseline scenario for the selected period of time (17.6 years) was estimated, followed by a policy scenario. Then, the net impact was calculated by subtracting the policy scenario values from those of the baseline scenario. These steps were also followed to calculate the current net impact from 2014 to 2018 (5 years). Table 26 shows the net impacts both calculated for 5 and 17.6 years. It should be noted that for every category, impacts caused by the raw materials extraction, production, and transport of the LED lamps were only included in 2014, when these stages are assumed to have happened. In contrast, these same impacts were included in 2021 and 2028 for the FL lamps, based on their lifespan of 20,000 hours. Similarly, impacts from the recycling of aluminium used in the LED lamp was included in 2031, when this is assumed to take place. Table 26 also shows that the policy scenario has a positive effect on four of the eight categories, if analysed from the date of installation to the present day (i.e. 5 years). However, all categories with the exception of mineral resources depletion have a positive impact over the entire lifespan of the LED lamps (i.e. 17.6 years), even if the early stages of the LED lamps (raw material extraction, production, and transport) are considered.

Table 26 Summary of environmental impacts generated by Climate Action 2 - LED panels. Net impacts are calculated for 5 years (2014-2018) and 17.6 years (2014-2031).

IMPACT	UNIT	BASELINE SCENARIO (5 yrs)	POLICY SCENARIO (5 yrs)	NET IMPACT (5 yrs)	% NET IMPACT (5 yrs)	BASELINE SCENARIO (30 yrs)	POLICY SCENARIO (30 yrs)	NET IMPACT (30 yrs)	% NET IMPACT (30 yrs)
GHG EMISSIONS	t CO_2 eq	239	146	**93**	**39%**	724	409	**315**	**43%**
DEPLETION OF MINERAL RESOURCES	kg Cu eq	66	243	**-177**	**-267%**	288	315	**-27**	**-9%**
DEPLETION OF FOSSIL RESOURCES	kg oil eq	74,990	46,104	**28,886**	**39%**	226,106	128,755	**97,351**	**43%**
FRESHWATER CONSUMPTION	m^3	531	467	**64**	**12%**	1,851	1,170	**681**	**37%**
LAND USE	m^2a crop eq	443	690	**-247**	**-56%**	4,888	2,900	**1,988**	**41%**
AIR QUALITY	DALY	0.24	0.16	**0.08**	**34%**	0.64	0.37	**0.27**	**42%**
HUMAN TOXICITY	DALY	0.025	0.029	**-0.004**	**-15%**	0.088	0.061	**0.027**	**30%**
WATER ECOTOXICITY	kg 1,4-DCB	6,255	7,190	**-936**	**-15%**	24,739	18,549	**6,190**	**25%**

The assessed impact categories can be broadly separated into three groups. In the first group, the policy scenario has positive impacts compared to the baseline scenario, if analysed from 2014 to 2018 (i.e. 5 years) as well as from 2014 to 2031 (i.e. 17.6 years). An example of this is shown in Figure 19 which presents the results for GHG emissions impacts. This is also the case for depletion of fossil resources, freshwater consumption, and air quality (figures presenting the results are found in Appendix 6).

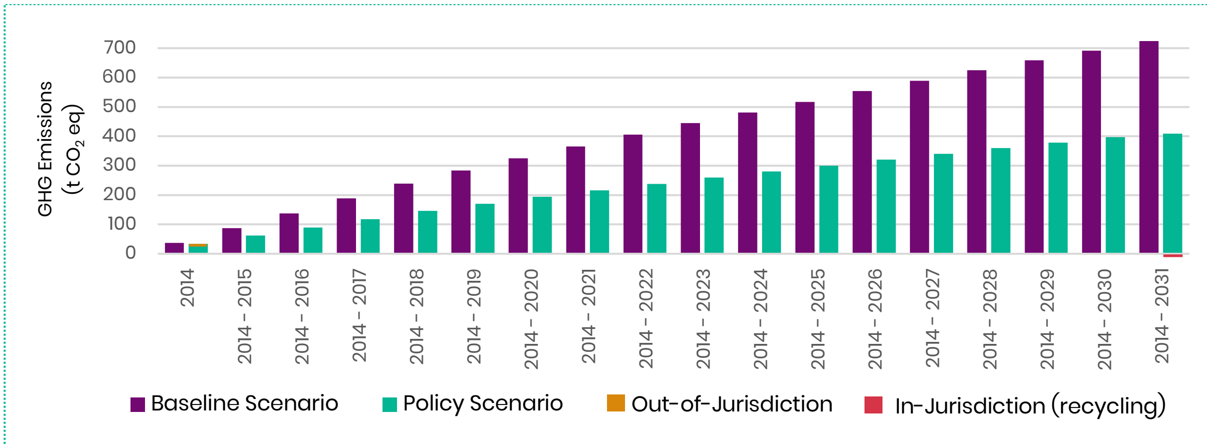

Figure 19 Accumulated GHG emissions impacts of Climate Action 2 - LED Lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.

In the second group, the categories have a positive net impact over their entire lifespan (i.e. 17.6 years). However, if analysed only from 2014 to 2018 (i.e. 5 years), the policy scenario results in negative impacts compared to the baseline scenario. Examples of this situation are shown in Figure 20 and Figure 21, which present the results for impacts on land use and human toxicity impacts, respectively. As can be observed from Figure 20, the policy scenario initially causes negative effects compared to the baseline scenario from 2014 to 2020. These negative impacts are mostly caused by diodes and aluminium production. However, as can be noted in this same figure, the negative trend will change over time before the 17.6 years lifetime of the LED lamps are reached, specifically in 2021. Similar to these impacts on land use, Figure 21 shows the results for human toxicity (carcinogenic and non-carcinogenic) impacts. As seen in Figure 21, the policy scenario results in net negative impacts from 2014 to 2019; however, from 2020 onwards, the policy scenario presents positive net impacts. The year when the policy scenario will become beneficial for the remaining category, water ecotoxicity, is 2020. The latter two categories, human toxicity as well as water ecotoxicity, are also negatively affected in the early years of the policy scenario as a consequence of diodes and molybdenum production.

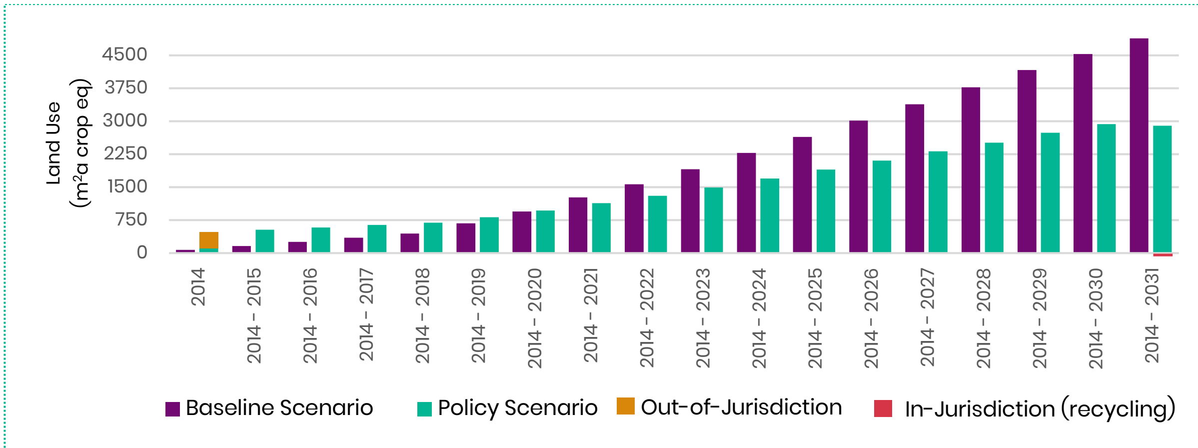

Figure 20 Accumulated land use impacts of Climate Action 2 - LED Lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.

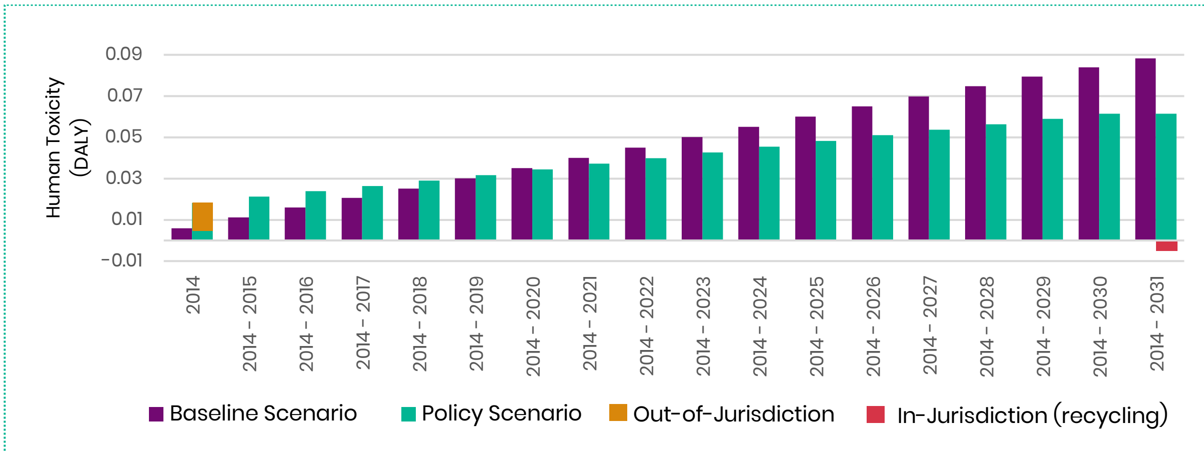

Figure 21 Accumulated human toxicity impacts of Climate Action 2 - LED Lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.

In the third group, the remaining category, mineral resources depletion, has both a negative impact if assessed from 2014 to 2018 (i.e. 5 years) as well as from 2014 to 2031 (i.e. 17.6 years). This negative effect in the category, shown in Figure 22, is caused by the metal high-based LED lamps, both in their aluminium heatsink as well as the molybdenum and silver-based solder paste used for the diodes. Although it is assumed that the aluminium is recycled, this positive impact does not offset the negative effects of this category.

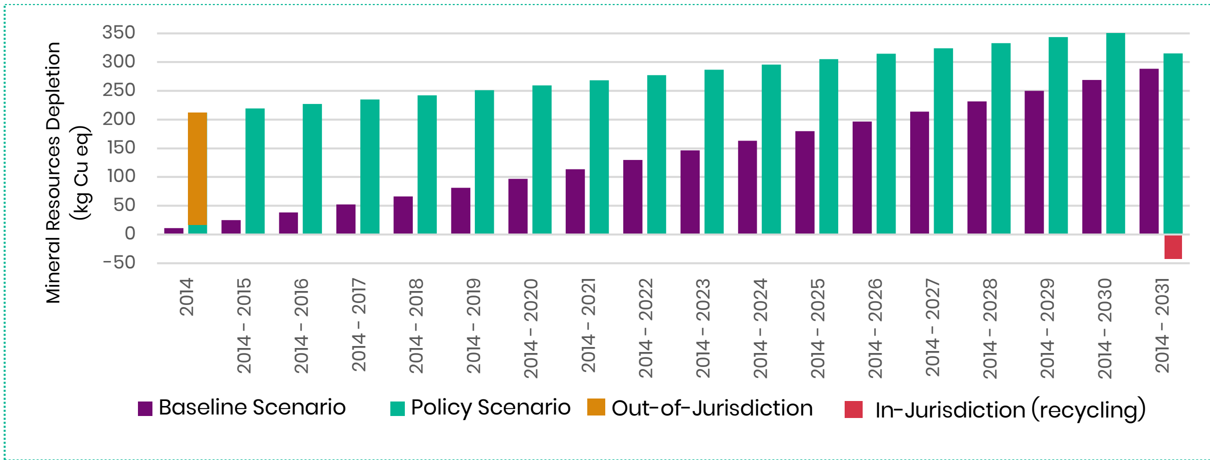

Figure 22 Accumulated mineral resources depletion impacts of Climate Action 2 - LED Lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.

Figures 20, 21, and 22 also show the in-jurisdiction and out-of-jurisdiction impacts attributed solely to the LED lamps in the policy scenario. On the one hand, out-of-jurisdiction impacts are those generated by the raw materials extraction, manufacturing, and transport of the LED lamps, which are assumed to have happened outside of Mexico. These types of impacts are coloured in yellow in the aforementioned figures. On the other hand, in-jurisdiction impacts from the LED lamps are constituted by the recycling of the aluminium heatsink and caps. These latter effects, which are coloured in red in the figures, are beneficial to the policy scenario since the recycling partly mitigates the negative impacts caused by the production of the lamps. Table 27 presents the in-jurisdiction and out-of-jurisdiction impacts generated by the LED lamps alone.

Table 27 Summary of LED lamps life cycle environmental impacts categorised by in-jurisdiction and out-of-jurisdiction impacts.

IMPACT	UNIT	TOTAL IMPACT	OUT-OF-JURISDICTION IMPACTS (RAW MATERIALS EXTRACTION, MANUFACTURING & TRANSPORT)	IN-JURISDICTION IMPACTS (RECYCLING)
GHG EMISSIONS	t CO^2 eq	13.3	18.8	-5.5
DEPLETION OF MINERAL RESOURCES	kg Cu eq	156.7	206.7	-50
DEPLETION OF FOSSIL RESOURCES	kg oil eq	3,361.3	4,519.8	-1,158.5
WATER CONSUMPTION	m^3	146.3	173.7	-27.4
LAND USE	m^2a crop eq	406.3	453.9	-47.6
AIR QUALITY	DALY	0.019	0.026	-0.007
HUMAN TOXICITY	DALY	0.012	0.015	-0.003
WATER ECOTOXICITY	kg 1,4-DCB	2,296.2	3,726.9	1,430.7

- ECONOMIC IMPACTS

Following the results from the qualitative assessment, the following specific impacts were assessed quantitatively: (i) electricity savings and (ii) cost savings. Furthermore, indicators such as SPB, NPV, and policy cost-effectiveness were also estimated.

Table 28 summarises the impacts and indicators calculated for the second climate action; installation of LED lamps. It can be observed that these lamps generated electricity savings of over 169,000 kWh from 2014 to 2018 (i.e. 5 years). Hence, generating cost savings of over MX$ 332,261 in the same period. These electricity savings are expected to increase up to 632,381 kWh as well as MX$1,485,385 from 2014 to 2031 (i.e. 17.6 years). In order to determine the profitability of this first retrofit, SPB and NPV were calculated. As can be seen from Table 28, payback time is short (i.e. 2.5 years); hence, the installation of LED lamps can be considered economically justifiable. This second climate action has an NPV of MX$1,307,682 calculated over the lifetime of the lamps, which is estimated to be 17.6 years (50,000 hours).

In terms of policy cost-effectiveness, the indicator was only analysed using the period of time that equals the lifetime of the LED lamps (i.e. 17.6 years), since it is a fairer option to describe the impact of this indicator. Policy cost-effectiveness of the PV panels was estimated to be 565 Mexican Pesos per tCO_2 mitigated. It is important to note, that these cost-effectiveness calculations assume changes in the electricity mix, thus, the amount of CO_2 mitigated values during the assessed period varies. However, no replacements were assumed.

Table 28 Summary of economic impacts generated by Climate Action 2 - LED panels. Net impacts are calculated for 5 years (2014-2018) and 17.6 years (2014-2031).

ECONOMIC INDICATOR	UNIT	BASELINE SCENARIO	POLICY SCENARIO	NET IMPACT
TOTAL INVESTMENT COSTS (year 1-2014)	MX$	N/A	N/A	177,698
REAL SOCIAL DISCOUNT RATE	N/A	N/A	N/A	3.3%
ELECTRICITY PRICE INCREASE RATE	N/A	N/A	N/A	3%
COST SAVINGS (year 1 - 2014)	MX$	N/A	N/A	70,501
ELECTRICITY SAVINGS (5 years)	kWh	0	169,229	169,229
COST SAVINGS (5 years)	MX$	0	332,261	332,261
ELECTRICITY SAVINGS (17.6 years)	kWh	0	632,381	632,381
COST SAVINGS (17.6 years)	MX$	0	1,485,385	1,485,385
SPB	yrs	N/A	2.5	N/A
NPV (30 years)	MX$	N/A	1,307,682	N/A
COST EFFECTIVENESS	MX$/$tCO_2$	N/A	565	N/A

4.5.5 Uncertainty and sensitivity analyses

Following the environmental and economic sensitivity analyses performed for the first climate action, the results of the second climate action were also compared using this type of analysis.

With regard to the environmental assessment, the results contain uncertainties due to the lack of location-specific data as well as the selection of global average values for the model. Furthermore, data gaps and uncertainties also exist in regard to the lamps bill of materials (BoM), despite efforts to model it precisely. Specifically, data on LED lamps was difficult to obtain since no peer-reviewed assessment of tube lamps currently exist.

Similar to the PV panels, other uncertainties relate to the end-of-life stage of the LED lamps. As described in the policy scenario, an assumption was made, where aluminium from the heatsink and the caps is recycled. Nevertheless, given the lack of a formal plan stated in the Carbon Management Plan for the disposal and recycling of the energy retrofit technologies, two environmental sensitivity analyses were performed. In these analyses, results from the assessment (where recycling of aluminium is assumed) are compared to a scenario where no recycling of this material occurs. Furthermore, a third scenario is analysed, where other metals in the diodes, such as iron, are recycled. Results from the environmental sensitivity analyses are presented in Table 29. It can be observed that the three scenarios have a negative effect on the depletion of mineral resources category; however, the scenario where most of the metals are recycled only show an impact of -9 kg of Copper equivalent, compared to a -27 kg Cu eq. from the policy scenario and -76 kg from the no-metal-recycling scenario. It can also be observed that recycling aluminium in the policy scenario leads to an increase in negative impacts within 6 categories, compared to the no-metal-recycling one. Only depletion of mineral resources as well as water ecotoxicity show positive impacts. However, this is not the case when an increase of metals are recycled, where it can be seen that the only category performing better is depletion of metal resources.

Table 29 Environmental sensitivity analyses - Recycling of metals in Climate Action 2 – LED Lamps.

SPECIFIC IMPACT	UNIT	NET IMPACTS – RECYCLING OF METALS	NET IMPACTS – RECYCLING OF ALUMINIUM (POLICY SCENARIO)	NET IMPACTS – NO RECYCLING OF METALS
GHG EMISSIONS	t CO^2 eq	316	315	309
DEPLETION OF MINERAL RESOURCES	kg Cu eq	-9	-27	-76
DEPLETION OF FOSSIL RESOURCES	kg oil eq	97,656	97,351	96,193
WATER CONSUMPTION	m^3	689	681	653
LAND USE	m^2a crop eq	2,004	1,988	1,940
AIR QUALITY	DALY	0.27	0.27	0.26
HUMAN TOXICITY	DALY	0.028	0.027	0.024
WATER ECOTOXICITY	kg 1,4-DCB	7,930	6,190	7,621

In regard to the economic assessment, three sensitivity analyses were performed, where the real social discount rate and the actual electricity price increase rate were changed in order to analyse how sensitive the economic results were to these two rates. Table 30 shows the results of these analyses, which followed the ones performed for the PV panels, where a "high" real social discount rate was selected (6%) based on recommendations given by an analysis from the World Bank (Lopez, 2008). Similarly, a "high" electricity price increase rate was selected (10%) based on recommendations and practical examples given by expert staff from Carbon Trust Mexico and the UNEP-DTU Partnership. From this economic analysis, it can be seen that the electricity increase rate is the parameter mostly affecting the results. It can also be inferred that economic benefits derived from the second climate action will grow if electricity prices increase at a rate higher than 3% in the following 13 years. Furthermore, none of the rate-combinations leads to a negative impact within the economic dimension, where cost savings range from 1,300,000 Mexican Pesos to 2,210,000 Mexican Pesos.

Table 30 Economic sensitivity analyses - Recycling of metals in Climate Action 2 - LED Lamps.

OPTION	COMBINATION OF RATES	RATE	UNIT	COST SAVINGS (17.6 years)	NPV
OPTION 1 (POLICY SCENARIO)	LOW Social Discount Rate	3.3%	MX$	1,485,380	1,307,682
	LOW Electricity Price Increase Rate	3%			
OPTION 2	LOW Social Discount Rate	3.3%	MX$	2,210,177	2,032,479
	HIGH Electricity Price Increase Rate	10%			
OPTION 3	HIGH Social Discount Rate	6%	MX$	1,300,344	1,122,646
	LOW Electricity Price Increase Rate	3%			
OPTION 4	HIGH Social Discount Rate	6%	MX$	1,872,049	1,694,351
	HIGH Electricity Price Increase Rate	10%			

4.6 Summary of sustainable development impact assessment

Previous sections described the qualitative and quantitative results of each climate action separately. This section presents a summary of these results in order to both, determine the total impacts caused by these actions and compare the contributions of each climate action. Table 31 summarises these results, where it can be observed that all specific impacts with the exception of rebound effects result in a positive total impact in regard to sustainable development. As explained previously, the category rebound effects bear the risk of having a negative impact since no track nor control of the savings generated by the climate policy currently exists within the government or Jalisco.

Analysing the environmental assessment impacts, the most significant benefits are related to the decrease in the use of electricity from the national grid, which is highly based on fossil fuels. Whilst the installation of PV panels reduced the electricity consumption from the grid by 6% each year for 30 years, the change of lamps (from FLs to LEDs) reduced consumption by 43% each year for 17.6 years. In contrast, the most significant negative impacts were caused by specific materials used for the manufacturing of PV panels and LED lamps. In most of the environmental impacts assessed, the materials used for LED lamps cause a greater environmental impact compared to FLs, especially affecting depletion of mineral resources. Silicon used for PV panels as well as metals used in the production of LEDs, such as copper, molybdenum, and silver-based solder paste are the highest contributors. It is important to note that even though the mass of the latter two metals might be small, the equivalent in kg of copper (as a unit to assess depletion of mineral resources) is much higher. The use of aluminium in the LEDs heatsinks is also a contributor of negative impacts, however, the recycling process assumed mitigates a fraction of these impacts.

With regard to the social dimension, it benefits from both climate actions. With an increase in climate change awareness of civil servants and public acceptance. Especially the latter impact which is currently supporting future climate projects with a greater scope in the State of Jalisco. Last, climate actions within the economic dimension generate savings of 2.5 million Mexican pesos. However, as previously mentioned, these cost savings are not currently being tracked, thus, it cannot be determined if these savings are being spent in actions supporting sustainable development.

Comparing the environmental and economic results of PV panels and LED lamps, it can be concluded that the benefits of LED lamps are far greater than those from PV panels. In all the quantified categories, with the exception of depletion of mineral resources, LED lamps have a bigger contribution to the positive results, even when the lifespan of 17.6 years is almost half of the PV panels lifespan of 30 years. However, this positive effect from LED lamps cannot be further scaled up, since no more lamps are needed in the building, thus, they have reached their maximum potential (without considering future technology improvements). In contrast, the positive effects of PV panels have the possibility to be scaled as long as there are available surfaces for this installation.

Table 31 Sustainable development impact assessment summary - full life cycle impacts.

DIMENSION	UNIT	SPECIFIC IMPACT	PV PANELS – NET IMPACT	LED LAMPS - NET IMPACT	TOTAL IMPACT
ENVIRONMENTAL	t CO_2 eq	GHG EMISSIONS	212	315	**527**
	kg Cu eq	DEPLETION OF MINERAL RESOURCES	42	-27	**15**
	kg oil eq	DEPLETION OF FOSSIL RESOURCES	66,683	97,351	**164,034**
	m^3	WATER CONSUMPTION	395	681	**1,076**
	m^2a crop eq	LAND USE	1,612	1,988	**3,600**
	DALY	AIR QUALITY	0.2	0.27	**0.47**
	DALY	HUMAN TOXICITY	0.02	0.027	**0.047**
	kg 1,4-DCB	WATER ECOTOXICITY	4,241	6,190	**10,431**

Table 31 (continued)

DIMENSION	UNIT	SPECIFIC IMPACT	PV PANELS – NET IMPACT	LED LAMPS - NET IMPACT	**TOTAL IMPACT**
ENVIRONMENTAL	kWh	RENEWABLE ENERGY CONSUMPTION	438,842	N/A	**N/A**
	--	RENEWABLE ENERGY SHARE (%)	6%	N/A	**N/A**
SOCIAL	--	CLIMATE CHANGE AWARENESS	POSITIVE	POSITIVE	**POSITIVE**
	--	PUBLIC ACCEPTANCE	POSITIVE	POSITIVE	**POSITIVE**
	--	LIGHTING QUALITY	N/A	POSITIVE	**POSITIVE**
ECONOMIC	--	JOBS	POSITIVE	POSSIBLY POSITIVE	**POSITIVE**
	--	LOCAL ECONOMY	POSITIVE	POSSIBLY POSITIVE	**POSITIVE**
	--	REBOUND EFFECTS	POSSIBLY NEGATIVE	POSSIBLY NEGATIVE	**POSSIBLY NEGATIVE**
	kWh	ELECTRICITY SAVINGS	438,842	632,381	**1,071,223**
	MX$	COST SAVINGS	1,039,980	1,485,385	**2,525,365**
	yrs	SPB	21.3	2.5	**N/A**
	MX$	NPV	417,139	1,307,682	**N/A**
	MX$/$tCO_2$	COST EFFECTIVENESS	2,931	565	**N/A**

5 Discussions

The previous chapter described the case study, followed the process underwent to identify and assess sustainable development impacts and presented the results of this assessment. This chapter discusses these results in order to provide recommendations aiming to improve other climate actions included in the Carbon Management Plan and/or other similar policies. These analyses and recommendations are explored in the first section. The second section focuses on the process outlined by the ICAT SD Guidance and reflects on key stages that shape the identification and assessment of impacts. The last two sections present the limitations of this study and recommendations for future research, respectively.

5.1 Results discussion and policy recommendations

The goal of this thesis was to identify and assess the impacts of a climate change mitigation policy on the three dimensions of sustainable development. These impacts were further disaggregated in research sub-questions based on geographical boundaries (in-jurisdiction and out-of-jurisdiction) as well as different periods of time, where an ex-post assessment looked into the impacts from 2014 to 2018 and an ex-ante assessment analysed the impacts from 2019 until the implemented technologies reached their end-of-life.

- ENVIRONMENTAL ASSESSMENT

The reason behind the geographical disaggregation of results was to highlight the negative environmental impacts low-carbon technologies have at early stages of their life cycles, which are not commonly accounted for when GHG emissions calculations of climate policies are analysed. As can be seen in the results, out-of-jurisdiction negative impacts were caused by the raw material extraction, manufacturing, and transport of PV panels and LED lamps. Impact categories such as depletion of mineral resources and water ecotoxicity were the most affected by these two technologies, given their heavy reliance on metals. However, it could be argued that these out-of-jurisdiction impacts still resulted in positive net impacts after they were compared to a long usage stage, where both technologies significantly reduced the adverse effects of a heavy fuel-based electricity mix. This phenomenon has gained attention in recent years and it is true to most, if not all, "green" or climate policies; where negative impacts incurred at early stages of a product or service turn into positive impacts at some point during their lifetime. However, this way of accounting for impacts has not been yet adopted by key stakeholders, such as governments. Furthermore, it is worth noting that in-jurisdiction and out-of-jurisdiction boundaries are political and are not followed by impact categories and the damage they cause. Whilst impacts such as human toxicity, land use, and water ecotoxicity can be identified as impact categories where effects are seen mostly locally (extending to a couple of hundred kilometers radius), impacts such as climate change have no notable spatial differentiation, thus, they affect the globe as a whole. Therefore, it is recommended to incorporate this full life cycle approach of accounting when climate policies, especially those ones focused on implementation of technologies, are assessed. By understanding the true life cycle impacts of these technologies, policymakers, governments, and companies can prevent the offset of benefits offered by climate policies.

Other commonly ignored life cycle stage of low-carbon technologies such as PV panels and LED lamps is the disposal stage. As previously mentioned, the Carbon Management Plan did not include any indication towards end-of-life management of the actions implemented. Nevertheless, general nation-wide or state-wide laws could regulate the proper handling of these products. However, during interviews with key stakeholders, it was highlighted that there was no clear guidance on which process to follow once the PV panels or the LED lamps have to be disposed.

As seen in the sensitivity analyses, recycling of aluminium, as a basic waste management strategy, is highly beneficial within the environmental dimension. Proper handling of this and more materials have the potential to mitigate negative impacts caused by the production stages. Based on this, it is recommended to develop, both at a state-wide level and at a policy-level, integral plans for the correct waste management of these technologies. However, recycling should not only be perceived as a method of recuperating valuable metals from the products but as a way of avoiding other social and environmental costs in the form of human health as well as air, water and soil pollution. It is also recommended to incorporate new forms of ownership in tendering processes needed for other actions within the Carbon Management Plan. These new requirements could include an extended producer responsibility clause where suppliers and/or producers handle the proper recycling and disposal of the products. Another option is to incorporate take-back systems or lease systems as viable options for owning assets in the government.

- SOCIAL ASSESSMENT

The geographical boundaries (i.e. in-jurisdiction and out-of-jurisdiction) delimiting an important part of the research in this thesis were also originally intended to analyse the social impacts by looking into the global supply chain of the PV panels and LED lamps installed. However, it was not possible to determine positive nor negative social effects internationally as a consequence of the production of these products. Although these types of impacts are commonly assessed through a Social Life Cycle Assessment (S-LCA), which is a method similar to LCA but looks into impacts on labour, human rights, governance, infrastructure as well as health and safety of regions caused by a product or a system; access to S-LCA databases was deemed costly. Furthermore, seldom university research group had access to them. Thus, including this perspective in the social assessment was not possible. Further limitations in this vein are explained in future sections. However, it is worth noting that even though no negative nor positive social impacts related to the production of PV panels and LED lamps were identified in this thesis, it is extremely needed that policymakers and decision-makers adopt a precautionary approach when developing climate policies or any type of policy. Contrary to the environmental assessment where a specific negative impact created in one part of the world can be somehow cancelled out by the same sort of positive impact in another part of the world; social impacts do not follow these rules. A negative impact affecting human rights of a single person or the well-being of a community cannot be cancelled out by those same effects (but positive) in another part of the world. Thus, it is recommended that policymakers and decision-makers at large take into consideration what these global supply chains can hide, and develop strategies in which not only green but fair (to all) procurement practices are followed.

Regarding social impacts included in this thesis, climate change awareness requires further focus. Although a positive impact caused by the climate change awareness-raising campaign was determined based on the analysis of relevant documents and interviews with stakeholders, it is worth mentioning that the ministries responsible of implementing the climate actions are in need of a stricter process for monitoring this change. For future actions, it is recommended to perform a baseline survey among civil servants in order to determine a baseline scenario where awareness and behaviours related to climate change and energy efficiency are measured. Furthermore, a series of follow-up surveys should also be conducted in order to measure any change in awareness or behaviour. These surveys should gather information on the following areas: (i) knowledge of climate change and its impacts; (ii) individual actions and behaviours; and (iii) knowledge of government programmes and initiatives related to climate change. Although this process is stated in the Carbon Management Plan, it was found that it is seldom followed.

- ECONOMIC ASSESSMENT

As mentioned in Section 4.6 environmental and economic positive impacts of LED lamps are greater than those generated by PV panels. However, positive effects of LED lamps cannot be further scaled up, since no more lamps are needed in the building. Thus, LED lamps present themselves as a "low-hanging fruit", the more cost-effective option. These types of options, in the context of carbon mitigation, are those which have a great potential for reducing environmental impacts without excessive costs. The government of Jalisco, guided by the Carbon Management Plan, Mexico's Climate Change Act guidelines and increasingly popular marginal cost abatement curves, did well at focusing first on implementing the most cost-effective climate actions (i.e. LED lamps) and at complementing them with the installation of PV panels as well as other planned actions with a greater scope and scale.

Regarding rebound effects, as mentioned multiple times in the previous chapter, it is recommended that the government of Jalisco develops a sustainable development or climate change fund where cost savings generated by climate actions and policies are directed to. The objective of this fund would be twofold, to avoid the expenditure of these savings on projects that can end up negatively affecting the planet and to support other climate and sustainable development policies.

- SYNERGIES AND TRADE-OFFS

The pursue of GHG emissions mitigation, the main objective of the assessed climate actions, resulted in many advantageous situations where other positive impacts were generated. This multiplicity of synergies include an increase in air quality, climate change awareness, public acceptance of energy retrofits, jobs, the local economy as well as a decrease in human toxicity, water ecotoxicity, land use, freshwater consumption, depletion of fossil resources, in addition to reductions in operational costs of electricity. However, as it has been mentioned, these synergies need to be analysed at different levels and through different perspectives. On the one hand, positive net impacts bear the risk of been considered negative ones if processes and practices associated with the manufacturing of these products are negatively affecting the environment and the communities in which they take place. On the other hand, other impacts, which are positive in nature, could perform better if both the current policy and parallel policies are more ambitious. This is the case of the effect on jobs and the local economy. Although the installation of PV panels resulted in a positive impact, these categories have the potential of performing better, if proper support of local R&D and education is given locally. The latter should not be the main focus of climate policies such as the Carbon Management Plan, however, policymakers should be aware of how it all relates and incorporate it in a way that multiplies positive impacts on sustainable development.

In regard to trade-offs, pursuing GHG mitigation generated negative net impacts, particularly in the depletion of mineral resources category. These impacts can be partially mitigated if recycling strategies are pursued. However, recycling is not enough. As previously mentioned, it is recommended to incorporate requirements in the tendering process which support an efficient use of material resources. Furthermore, these new requirements should also incorporate environmental and social considerations as guiding principles. Current procurement regulation in the State of Jalisco, The Governmental Procurement, Disposals and Services Act (*Ley de Compras Gubernamentales, Enajenaciones y Contratación de Servicios del Estado de Jalisco y sus Municipios*) (Gobierno del Estado de Jalisco, 2017), vaguely considers impacts on the environment as a criteria for choosing supplier only if the two most economical options have less than a 2% price difference between their offers. This regulation not only demonstrates that the economic dimension dominates governmental procurement practices but also indicates the need for reforming these practices to properly support and align with policies such as the Carbon Management Plan.

5.2 Process discussions

- DEFINING SUSTAINABLE DEVELOPMENT IMPACTS

The identification and assessment of sustainable development impacts in this thesis followed the ICAT SD Guidance within a case study. This tool is a guide that responds to a clear need of assessing impacts other than solely GHG effects and costs; indicators which have dominated the analysis of climate policies in the past years. Compared to other similar tools where impact identification and impact assessing processes are presented in a simplified and somehow superficial manner, the ICAT SD Guidance aids the practitioner to properly understand and compare multiple impacts caused to sustainable development through a clear and comprehensive step process.

Identifying these impacts undoubtedly leads to the challenge of defining sustainable development. Even though the guidance clarifies that it is a case-specific process as well as motivates the user to consider a balanced and extensive list of impacts from different perspectives, it clearly takes a stance of what sustainable development is, at least on a high level, where it is considered a balance of three main dimensions (environmental, social and economic). Parting from this definition, the practitioner needs to handle the conceptual complexity and interpreted flexibility of the term as well as select an appropriate interpretation of it, given the context and the audience it is aimed to. The practitioner also has to manage the interpreted flexibility of the specific policy being analysed, where the policy can be interpreted and constructed differently depending on the stakeholder involved. For example, PV panels can represent GHG emissions mitigation to specific stakeholders, good energy investments to other stakeholders, and use of renewable energy to others. This interpreted flexibility is what makes impact identification such a fuzzy process. However, this is not correct nor incorrect, but it represents the constant reflection and dialogue practitioners need to follow and be aware of in order to avoid biases.

In addition to the interpreted flexibility of both the concept of sustainable development and the policy itself, selecting impact categories within each dimension of sustainable development represented a challenging task. The use of LCA to assess environmental impacts greatly supported the identification of these impacts. However, this was not the case for the economic and social dimensions, which strongly depended on the perspective of different stakeholders. Furthermore, impacts from a specific dimension could also pertain to another dimension. This was the case of socio-economic impacts, which in this study were assigned to the economic dimension, but could have also been assigned to the social dimension. Other impacts assessed in the environmental dimension such as human toxicity and air quality, which were measured in DALYs, can be also understood as social impacts.

- IDENTIFYING AND ENGAGING STAKEHOLDERS

The initial identification of stakeholders made use of a rainbow diagram (Appendix 2) to recognise and classify specific people or groups of people that both are affected by the policy as well as influenced the policy to some extent. This activity resulted in an array of local and international stakeholders, which the ICAT SD Guidance recommends taking into consideration when identifying impact categories. However, it was not possible to contact nor include the opinions and interests of all these groups. Thus, these groups were not fully represented, given the lack of social location-specific data. This situation unfolds complex issues intrinsic to policies, particularly policies that introduce new technologies or services related to: (i) the inclusion of interests and social impacts of communities far away in the supply chain; (ii) the misrepresentation of these interests by actors not fully aware of the effects; (iii) the drawing of geographical boundaries only based on the relative relevance of a policy; and (iv) to the balancing of different interests that value impact categories differently.

- USING LCA

Performing an LCA, with access to appropriate software and databases, allowed this thesis to look into environmental impacts (i.e. water ecotoxicity) that were not initially deemed relevant nor significant by any of the consulted stakeholders, without demanding extra resources to perform the assessment. However, in the context of other analyses, carrying out an LCA can be a tedious and resource demanding activity, particularly with projects that are small or do not have access to an LCA practitioner.

5.4 Limitations of the study

As mentioned in previous chapters, this thesis focused on two out of 96 climate actions included in the Carbon Management Plan of the State of Jalisco. Although the selected actions represent the most common projects in this policy it should not be assumed that the results of this sustainable development impact assessment represent the entireness of the climate policy.

In the context of the two climate actions, social and economic dimensions were exclusively analysed in-jurisdiction, where local impacts (state-wide) were the main focus. Therefore, the social and economic assessments do not represent the whole life cycle impacts in the same fashion the environmental assessment does. However, this environmental assessment has also limitations since calculations were based on global averages from the database used (Ecoinvent v4.3). Nevertheless, specific predetermined quantities in the database (i.e. Mexican electricity mix and PV panels) were modified in order to better represent the analysed projects. With regard to lamps, a simplification of the installed models was performed on account of model complexity. Furthermore, the BoM of the LED lamps was estimated based on related LCAs and audiovisual material explaining common manufacturing processes these lamps are subject to.

Aside from the limitations of the environmental assessment, limitations within the economic assessment have to be considered as well. First, future regulations supporting net billing were not considered in the calculations. If these regulations come into effect they can positively affect cost savings in the future, where electricity not consumed over the weekends can be sold to the national grid. Second, as mentioned in the sensitivity analyses, which attempted to mitigate other uncertainties in the economic assessment, both discount rates, as well as electricity price increase rates, were assumed based on literature review and expert opinion. However, based on the lifespan of the technologies analysed, the rates can change and render different results. Furthermore, future assumptions such as electricity prices or electricity mix can change if future national governments reform laws affecting the energy sector.

5.5 Recommendations for further research

In the attempt to identify and assess sustainable development impacts of climate policies, this thesis, as an exploratory case study, has provided several answers; however, in the process, it has raised questions in the form of recommendations for further research. These recommendations address the limitations and information gaps found in the social dimension of the present assessment, which include: (i) incorporation of S-LCA in policy analysis; (ii) climate change awareness; (iii) media coverage of energy retrofits impacts on public acceptance; (iv) impacts of lighting in human health; and (v) development of just social and environmental practices in the government.

Due to lack of access to S-LCA databases, no life cycle social impacts related to the production of PV panels and LED lamps were included. To be fully able to assess these impacts, further research is needed on how to incorporate social life cycle aspects such as labour risks, human rights risks, health and safety risks, as well as governance risks in climate policy assessments. Furthermore, this research should consider situations where it is possible to determine the countries of origin (CoO) of products as well as situations in which it is not possible.

This thesis identified positive impacts related to climate change awareness of civil servants in the SEPAF building. However, as previously mentioned, a diligent and formal process is recommended to deepen the understanding of these impacts. Moreover, further research on the effect of energy retrofits on climate change awareness and behavioural change is needed to improve the design of these awareness-raising campaigns. In this vein, further research is also needed on how media coverage of this type of energy retrofits affects the general population's public acceptance and perception of technologies such as PV panels or LED lamps.

In this thesis, several impacts of artificial lighting were found, favouring the selection of LED lamps. However, other health impacts that artificial lighting poses to humans have yet to be assessed. Particularly a better understanding between light stimuli and responses of the human circadian system.

Last, recommendations for improved tendering processes that support sustainable development were mentioned multiple times in previous sections. Research on how to incorporate environmental and social dimensions to develop just procurement and tendering processes is needed. Furthermore, the research should not only focus on these processes but on other governmental practices that could multiply the benefits of climate policies (or any type of policy) and that could minimise negative effects.

6 Conclusions

This thesis has identified and assessed sustainable development impacts of two climate actions included in the Carbon Management Plan of the State of Jalisco, namely, the installation of PV panels and LED lamps in a public building. In doing so, the assessment was divided in two parts; an ex-post assessment, where impacts from 2014 to 2018 were determined as well as an ex-post/ex-ante assessment, where impacts from 2014 until the products' end-of-life were estimated. Concerning the environmental dimension, a full life cycle assessment was performed, where in-jurisdiction as well as out-of-jurisdiction impacts were calculated. In contrast, only in-jurisdiction impacts were assessed within the social and economic dimensions. Additionally, based on the results, diverse recommendations are given to inform better design and implementation of future climate policies and actions.

The thesis followed an exploratory single-case study methodology, where the two main units of analysis represented each climate action. Furthermore, each unit of analysis contained three sub-units of analysis representing the dimensions of sustainable development. Additionally, the ICAT SD Guidance was used within the case study to identify and present the impacts assessed. Furthermore, these impacts were assessed differently based on the dimension of sustainable development they pertained to: (i) environmental impacts were calculated through an LCA; (ii) social impacts were determined based on literature review, interviews as well as analysis of documents and archival records; and (iii) economic impacts were partly calculated using cost-effectiveness indicators and partly determined based on interviews.

As mentioned previously, key steps from the ICAT SD Guidance were followed to identify each of the impacts assessed in this thesis. The process outlined in the tool includes the following main steps: (i) selection of the policy and/or climate actions; (ii) definition of impact categories; (iii) assessment of impact categories based on significance, relevance, and comprehensiveness; (iv) definition of specific impacts through causal chain diagrams; (v) evaluation of magnitude, likelihood and nature of change of each impact within the qualitative assessment; and (vi) estimation of impacts quantitatively. The ICAT SD Guidance was used based on its comprehensiveness, detailed process outline, and as a pilot case to support the further development of this tool.

The sustainable development impact assessment performed in this thesis rendered multiple results. Within the social dimension, both PV panels and LED lamps greatly contributed to a climate change awareness-raising campaign aimed towards a behavioural change of civil servants, which in turn had positive impacts in GHG emissions mitigation as well as electricity savings. Furthermore, these two climate actions had positive impacts on public acceptance, particularly public acceptance of private investors, whose support is currently being sought for the financing of further climate actions included in the Carbon Management Plan. Moreover, the installation of LED lamps resulted in positive impacts on human health and task visibility of civil servants. In regard to the economic assessment, the two climate actions generated savings of 2.5 million Mexican pesos, with payback times of 2.5 years for LED lamps and 21.3 years for PV panels. Thus, both actions were deemed economically viable. Moreover, positive impacts on jobs and the local economy were also found. Finally, the environmental assessment rendered the following results. In the ex-post assessment (i.e. 5 years) positive impacts on GHG emissions, air quality, and depletion of fossil resources were found, however negative net impacts were identified in categories such as human toxicity, water ecotoxicity, land use, and depletion of mineral resources. Nevertheless, the results of the ex-post assessment were analysed together with the ex-ante results. As a consequence, all impact categories with the exception of depletion of mineral resources from the LED lamps generated positive net impacts. The environmental assessment also presented out-of jurisdiction impacts generated by the raw material extraction, production, and transport of the PV panels and LED lamps.

The multiplicity of significant results included in this assessment contributes to the policy design implementation cycle in various ways. In contrast to the common practice of exclusively measuring mitigation of GHG emissions and cost savings, the assessment presents other environmental, social and economic impact categories that should be considered when assessing climate policies. Furthermore, this thesis introduces full life cycle impacts, which are particularly needed for environmental and social assessments, if proper net impacts need to be determined and/or out-of-jurisdiction impacts need to be disaggregated for further considerations. Moreover, the assessment contributes to policy design by including several recommendations for just and sustainable governmental practices, especially practices related to procurement and tendering processes. The analysis also stresses the importance of proper end-of-life management of the installed technologies, which have the potential to mitigate negative environmental, social, and economic impacts. Furthermore, assessing the sustainable development impacts of climate actions such as the ones included in this thesis, represent benefits for governments seeking to obtain funding for climate change related projects. These types of funding require a high degree of transparency about policies and results, such as the transparency framework included in article 13 of the Paris Agreement supporting the global "stocktake" of Article 14 in said agreement.

Although the assessment covered impacts on the three dimensions of sustainable development, certain constraints limited it. Social and economic dimensions exclusively assessed in-jurisdiction impacts, since the information needed for out-of-jurisdiction effects of the policy was not available. Furthermore, several uncertainty factors linked to the assessment limited the results. Data used to model the environmental assessment was based on global averages from the database used (Ecoinvent v4.3), thus, scant location-specific data was used. Concerning lamps, a simplification of the installed models was performed on account of model complexity. Other uncertainty factors within the economic assessment included discount rates as well as electricity price increase rates, which were assumed based on literature review and expert opinion.

As a final remark, this sustainable development impact assessment can be deemed successful. As an exploratory case study, it has also identified areas for further research which are recommended to be incorporated in climate policy design, implementation, and evaluation. These areas of research include the assessment of social impacts caused by policies from a life cycle perspective (i.e. S-LCA), the effects of energy retrofits and climate change awareness-raising campaigns in behavioural change, impacts of artificial lighting in the human circadian system; as well as the development and adoption of just and sustainable governmental practices.

Overall, this assessment has shown the importance of analysing the sustainable development impacts of policies. It has shown that limiting the analysis of climate policies to a few environmental and economic factors disregards other areas of human life and the earth's system that are positively and/or negatively impacted. Ultimately, ignoring these extended impacts can inadvertently affect us all.

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Appendix 1 Comparison of sustainable development impact assessment tools

Table 1. 1 Comparison of sustainable development impact assessment tools.

	ICAT SD GUIDANCE	NAMA SD EVALUATION TOOL	FRAMEWORK FOR MEASURING SD IN NAMA'S	CDM SD Tool	GHG PROTOCOL POLICY AND ACTION STANDARD
TYPE OF TOOL	Guidance	Spreadsheet	Framework	Online form	Guidance
PURPOSE OF ASSESSMENT	Assess the sustainable development impacts of a policy and action.	Evaluate the sustainable development results achieved by a NAMA.	Assess the sustainable development impacts of a NAMA.	Describe the sustainable development co-benefits of a CDM.	Estimate GHG emissions effects from a policy and action.
SUBJECT OF ASSESSMENT	Policies and actions	Climate change mitigation actions	Climate change mitigation actions	Climate change mitigation actions	Climate change mitigation policies and actions
COVERAGE AREAS	Specific policy instruments, technologies, processes, and practices	National and Sub-national Policies	National and Sub-national Policies	Projects and programmes	Specific policy instruments, technologies, processes, and practices
DIMENSIONS OF SUSTAINABLE DEVELOPMENT	3	5 (including institutional, and growth & dev.)	4 (including institutional impact)	3	3
TYPE OF ASSESSMENT	Qualitative and quantitative, use of indicators, baselines, and target values	Qualitative and quantitative, use of indicators and baselines, and target values	Qualitative and quantitative scoring, use of indicators	Qualitative scoring, use of indicators	Mostly quantitative
IMPACT CATEGORIES	Yes (user-defined, but suggested list)	No	Yes (16 criteria)	Yes (12 criteria)	No
INDICATORS	Yes (user defined)	Yes (user defined)	Yes (87 defined, plus option to add others)	Yes (70 defined)	Yes (user defined)

PRESCRIPTION OF SPECIFIC CALCULATION METHODS OR SUB-METHODS	No (certain methods are suggested)	No	No (certain methods are suggested)	No	No (certain methods are suggested)
TEMPORAL CHARACTERISTICS	Ex-ante and Ex-post	Ex-ante and Ex-post	Ex-ante and Ex-post	Ex-post	Ex-ante and Ex-post
STAKEHOLDER PARTICIPATION	Yes, stages identified	No	Yes, suggested	No	Yes, briefly suggested
DEGREE OF LINKAGE WITH SDGS	Medium (used as one of the ways to identify impact categories)	Strong (indicators selections based on them)	Strong	None	None

Appendix 2 Stakeholders identification

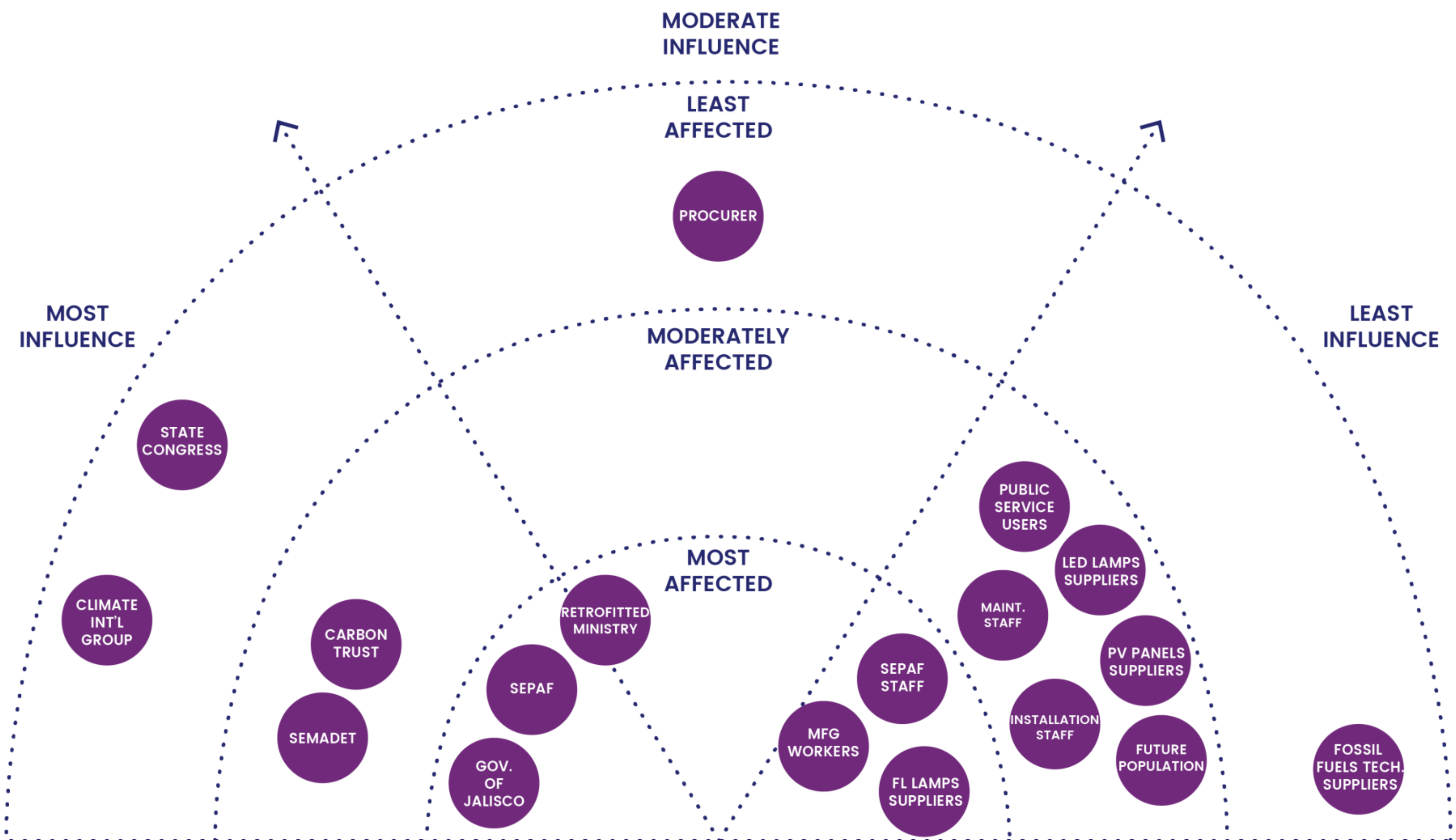

Figure 2. 1 Rainbow diagram including relevant stakeholders to the case study.

Appendix 3 Interview protocol – impact categories evaluation

Briefly explain the ICAT SD Guidance and present an overview of the steps followed in the assessment. Specify the steps where the opinions of stakeholders are needed and highlight the step we are currently at. Present the two selected climate actions and the reasons behind this selection. Have a presentation prepared where the instructions are clearly stated and where the interviewee can observe the progress of the assessment in real time.

1. Can you start by telling me about your role at the ministry/organization/company?

2. What was or has been your relationship with the Carbon Management Plan?
    a. What about the installation of PV panels and LED lamps in the SEPAF building?

Present the list of impacts categories and explain it is a non-exhaustive list of possible impacts. Explain that we will discuss all the impacts with the selected actions in mind. Then, present the criteria that will be followed in the assessment: (i) significance; (ii) relevance.

3. We will first review the PV panels and then the LED lamps. Regarding the PV panels and the <u>(environmental/social/economic)</u> assessment, how significant are the impacts on ______?

Continue with all the dimensions and categories. After the first action is assessed, give a summary of the results.

4. So far, we have identified the following impacts... Is there any other you would like to add? Is there any impact you think needs further research to determine its significance?

Review the second climate action following the same instructions. After the second action is assessed, explain the criterion of comprehensiveness and review the list again with them. If one dimension has notably more impact categories, ask what the reasons behind this are.

5. Is there any other impact you would like to add to this list?

After the consultation, explain that the assessment requires more types of stakeholders. Introduce the rainbow diagram as a tool to identify these stakeholders based on the degree of influence in the policy and how much they are affected (positively or negatively) by the policy. Tell them that you will review the diagram with them.

6. Here is a selection of stakeholders identified in advanced, we will locate them in the diagram based on how much they influence the policy and how much they are affected by it. The first stakeholder, where should it be located?

7. Are there other key stakeholders that should be included in the diagram?

8. From all the stakeholders, is there any contact information you can share in order to interview them?

Additional questions for Carbon Trust and SEMADET:

1. How were the actions assessed in the Carbon Management Plan?

2. Who selected the impact categories to assess the actions?

3. In your opinion, which are the impact categories that matter the most in the context of climate policies and why?

Additional questions for SEPAF and SEMADET:

1. When were the PV panels and the LED lamps installed?

2. What type of maintenance is given to these products?

3. Is there any plan/guideline/regulation followed for the disposal of these products?
    a. If there is no plan, what do you do with them?

At the end of the interview, thank the stakeholder(s) and tell them that you will send a summary of the interview and a presentation with the results for them to review. Remind them the ICAT SD Guidance steps and that another consultation will be needed in the future. Arrange time and date for this consultation.

Appendix 4 Interview protocol – qualitative assessment

Remind them about the ICAT SD Guidance and present an overview of the steps followed in the assessment. Specify the steps where the opinions of stakeholders are needed and highlight the step we are currently at. Present the two selected climate actions and the reasons behind this selection. Have a presentation prepared where the instructions are clearly stated and where the interviewee can observe the progress of the assessment in real time.

Present the list of impacts categories selected based on the opinion of stakeholders and the desktop study. Present the causal chain diagrams explaining the specific impacts within each dimension of sustainable development and explain that those specific impacts will be analysed.

1. Are there other impacts you would like to add to these causal chain diagrams? Why?

Present the criteria that will be followed in the assessment: (i) likelihood; (ii) magnitude; and (iii) nature of change.

2. We will first review the PV panels and then the LED lamps. Regarding the PV panels, what is the likelihood of ______ impact happening?

3. What is the magnitude of _______ impact?

4. Is this a positive or a negative impact?

Continue with all the specific impacts. After the first action is assessed, give a summary of the results and ask the following questions:

5. Are there any documents or studies that can support these statements? Could you share them with me?

Then, assess the second action following the same instructions.

6. So far, we have assessed the following specific impacts... Is there any other you would like to add? Is there any impact you think needs further research to determine its significance?

At the end of the interview, thank the stakeholder(s) and tell them that you will send a summary of the interview and a presentation with the results for them to review. Ask if you can contact them if you have more questions and remind them about the dates for your final thesis, specifying that you will share the final document with them.

Appendix 5 Interview protocol – climate change awareness SEPAF

Briefly explain the ICAT SD Guidance and present an overview of the steps followed in the assessment. Update the stakeholder with the current status. Explain that you have questions regarding the climate change awareness raising-campaign and the impacts it has caused.

1. Can you start by telling me about your role at the ministry/organization/company?

2. What was or has been your relationship with the Carbon Management Plan?
    a. What about the climate change awareness-raising campaign?

3. Can you explain to me in detail the climate change awareness-raising campaign?
    a. Are there any documents you could share with me related to this campaign?

4. Who is the target audience for this awareness-raising campaign?

5. Which actions have been followed (included or not in the campaign) to sensitize civil servants regarding their local and global impact related to electricity use?

6. Who is responsible for this campaign in the SEPAF?
    a. What about at a state-level?

7. How and how often do you measure the impacts of this awareness campaign?
    a. Did you establish a baseline scenario? If so, can you tell me more about this and if possible share the results?

Ask follow-up questions if needed and contacts of people relevant to this impact. Thank the stakeholder for participating in the interview. Ask if you can contact them if you have more questions and remind them about the dates for your final thesis, specifying that you will share the final document with them.

Appendix 6 Environmental impacts

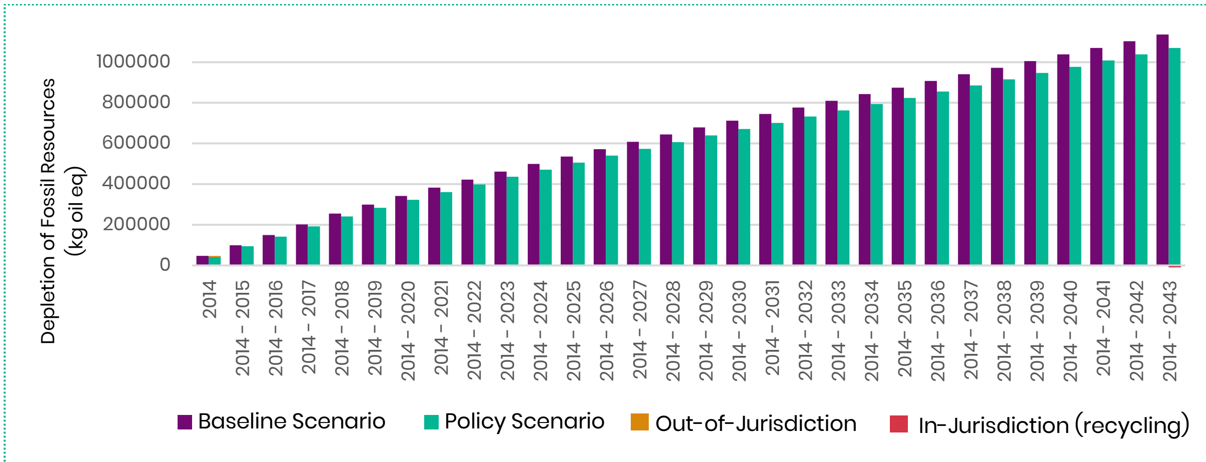

Figure 6. 1 Accumulated fossil resources depletion impacts of Climate Action 1 – PV Panels. Production impacts from PV panels are included in 2014 and disposal impacts in 2043.

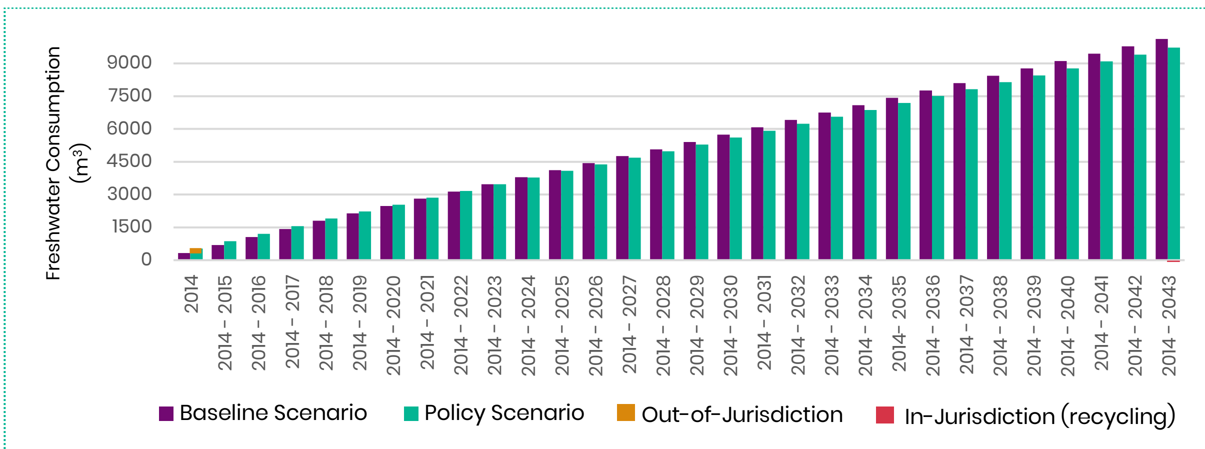

Figure 6. 2 Accumulated fossil resources depletion impacts of Climate Action 1 – PV Panels. Production impacts from PV panels are included in 2014 and disposal impacts in 2043.

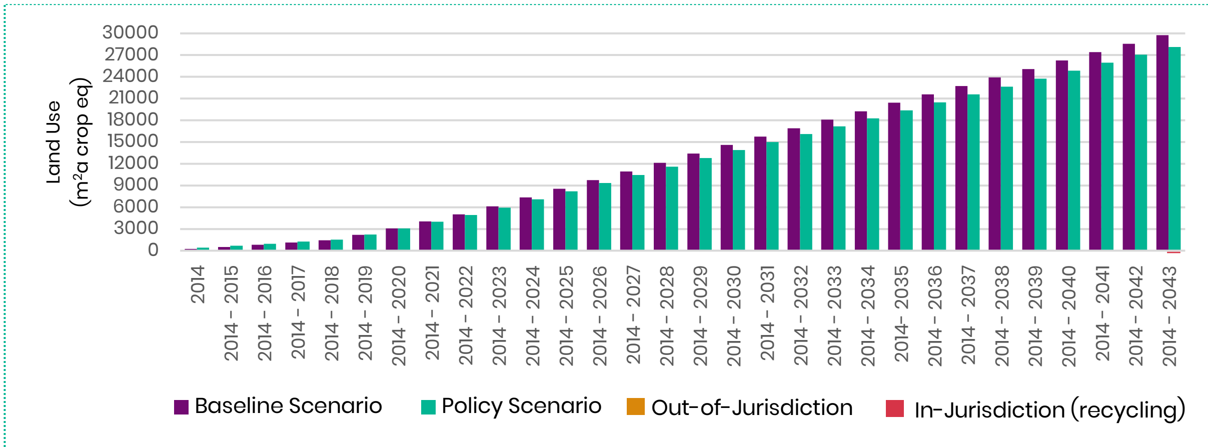

Figure 6. 3 Accumulated land use impacts of Climate Action 1 – PV Panels. Production impacts from PV panels are included in 2014 and disposal impacts in 2043.

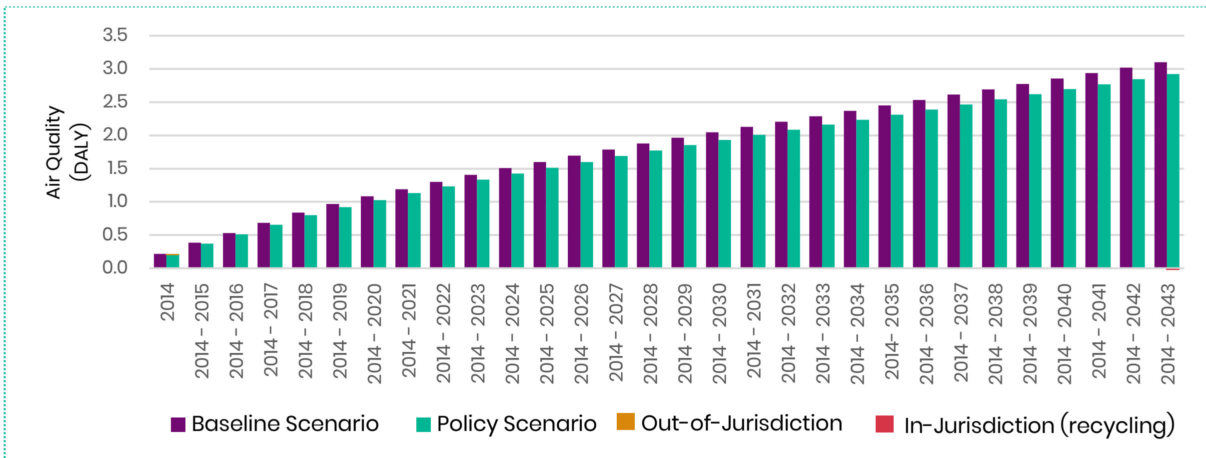

Figure 6. 4 Accumulated air quality impacts of Climate Action 1 – PV Panels. Production impacts from PV panels are included in 2014 and disposal impacts in 2043.

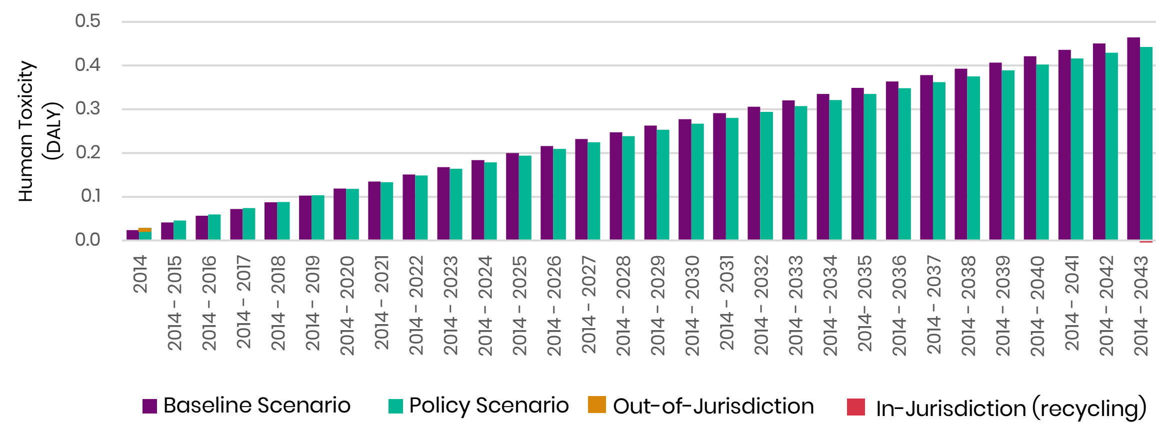

Figure 6. 5 Accumulated human toxicity impacts of Climate Action 1 – PV Panels. Production impacts from PV panels are included in year and disposal impacts in 2043.

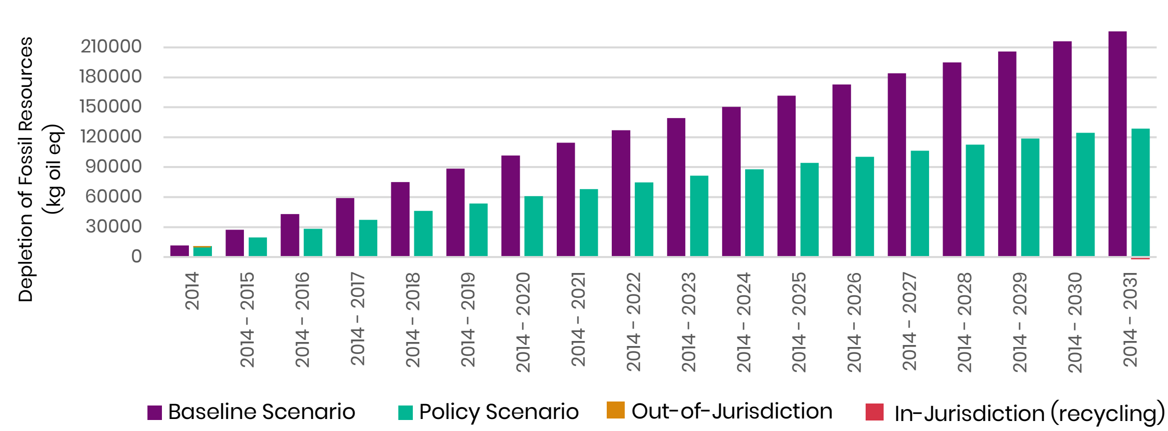

Figure 6. 6 Accumulated fossil resources depletion impacts of Climate Action 2 - LED lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.

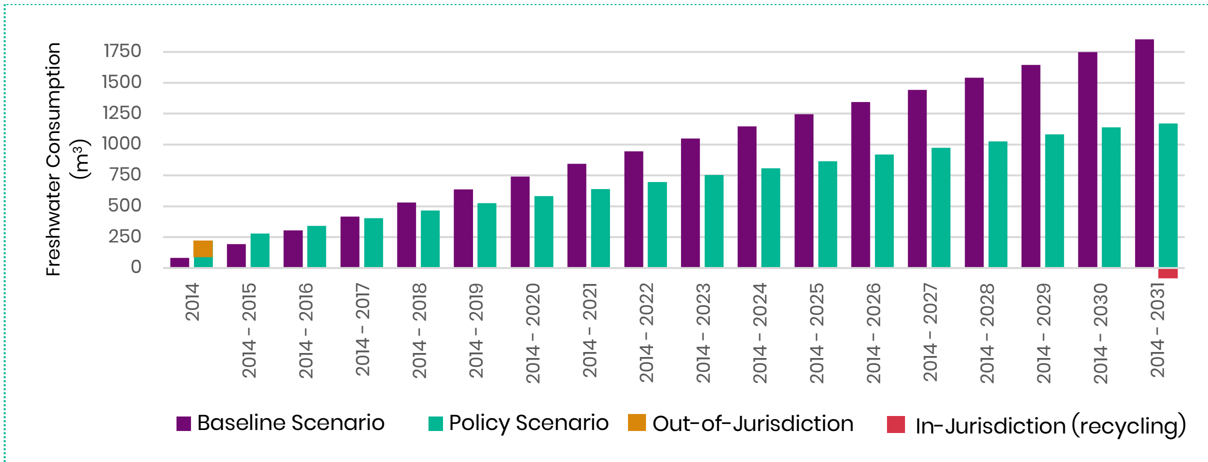

Figure 6. 7 Accumulated freshwater consumption impacts of Climate Action 2 - LED lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.

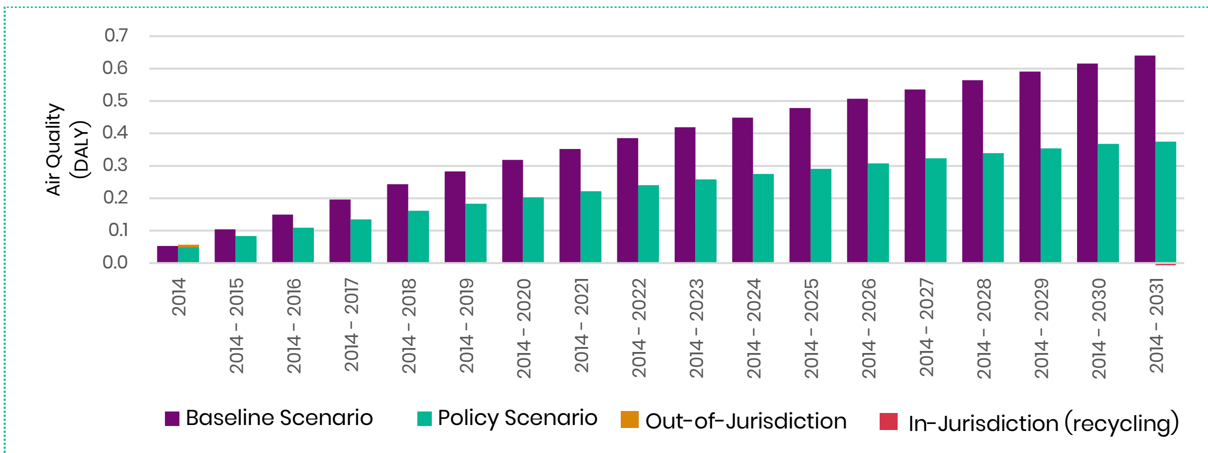

Figure 6. 8 Accumulated air quality impacts of Climate Action 2 - LED lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.

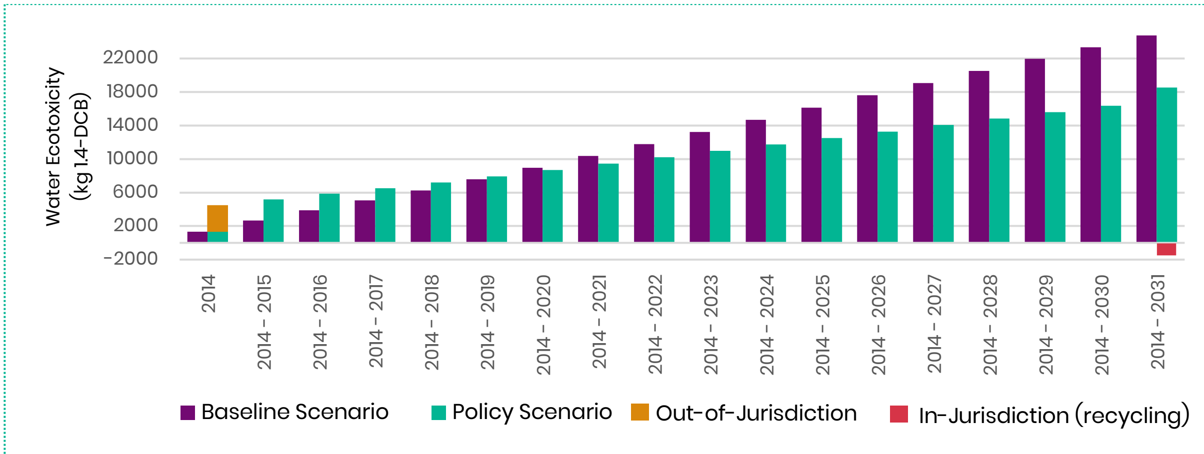

Figure 6. 9 Accumulated water ecotoxicity impacts of Climate Action 2 - LED lamps. Production impacts from LED lamps are included in 2014 and disposal impacts in 2031.